

ESTIMATES OF NITROUS OXIDE EMISSIONS FROM MOTOR VEHICLES AND THE EFFECTS OF CATALYST COMPOSITION AND AGING

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GLOSSARY OF TERMS, ABBREVIATIONS, AND SYMBOLS

A/F	Air-to-fuel ratio
ARB	California Air Resources Board
CAS	Chemical abstract service
CCS	Climate change species
CFR	Code of federal regulations
CH ₄	Methane
CLD	Chemiluminescent detector
CLS	Classical least squares
CO	Carbon monoxide
CO ₂	Carbon dioxide
CVS	Constant volume sampler
DFR	Data for record
EGR	Exhaust gas recirculation
EIA	Energy information administration
FHWA	Federal highway administration
FID	Flame ionization detector
FTIR	Fourier transform infrared spectroscopy
FTP	Federal test procedure
THC	Total hydrocarbons
HONO	Nitrous acid
HSL	Haagen-Smit Laboratory
IPCC	Intergovernmental panel on climate change
IRD	Infrared detector
IW	Inertia weight
KBr	Potassium bromide
KPH	Kilometer per hour
LDT	Light-duty truck
LDT1	Light-duty truck up through 3,750 lbs loaded vehicle weight
LDT2	Light-duty truck greater than 3,750 lbs loaded vehicle weight

LDV	Light-duty vehicle
LEV	Low emission vehicle (California designation)
LOD	Limit of detection
MCT	Mercury cadmium telluride
MLD	ARB's Monitoring and Laboratory Division
MN ₂ O	Modal driving cycle for N ₂ O testing
N	Sample size
N ₂	molecular nitrogen
N ₂ O	Nitrous oxide
NH ₃	Ammonia
NIST	National institute of standards and technology
NM VOC	Non-methane volatile organic compounds
NO	Nitric Oxide
NO ₂	Nitrogen dioxide
NO _x	Nitrogen oxides
OEM	Original equipment manufacturer
PC	Passenger car
Pd	Palladium
ppb	Parts per billion
ppm	Parts per million
Pt	Platinum
PVF	Polyvinyl fluoride (film)
QC	Quality control
r	Regression coefficient
r ²	Correlation coefficient
Rh	Rhodium
RLF	Road load force
RMS	Root mean square
RMT	Remote mixing tee
SOP	Standard operating procedure
SULEV	Super ultra low-emission vehicle (California designation)

SUV	Sport utility vehicles
THC	Total hydrocarbons
TIER0	Tier 0-certified vehicles (federal designation)
TIER1	Tier 1-certified vehicles (federal designation)
TLEV	Transitional low emission vehicle (California designation)
TWC	Three-way catalyst
UC	Unified Cycle
UDDS	Urban dynamometer driving schedule – also known as LDV FTP
ULEV	Ultra low emission vehicle (California designation)
USEPA	U.S. environmental protection agency
VIN	Vehicle identification number
VMT	Vehicle miles traveled
VSP	Vehicle surveillance program
VTs	ARB’s vehicle testing system database
VVT	Variable valve timing
ZEV	Zero emission vehicle (California designation)
σ	Standard deviation

ABSTRACT

FTIR spectroscopy was used to determine nitrous oxide concentrations in dilute exhaust samples collected from vehicles tested as part of the last two California vehicle surveillance programs. We conducted more than 400 dynamometer experiments for 134 light-duty vehicles, including passenger cars and light-duty trucks. In addition to exhaust species concentrations, we collected exhaust and catalyst temperature data, fuel sulfur content, and air-to-fuel ratio data. Type of vehicle, driving cycle, applicable emissions standard, and especially catalyst temperature were found to be the most important factors determining N₂O emissions from gasoline powered light-duty vehicles. In all cases, the highest catalyst temperature range (> 650 °C) was associated with lower nitrous oxide emission factors whereas intermediate catalyst temperatures (120 °C to 550 °C) were associated with elevated N₂O emissions, and little or no emissions were observed below 120 °C. The mean nitrous oxide emissions factor from all vehicles tested was 20 mg km⁻¹ (N = 264; σ = 22), lower than reported in previous research. The current trend of decreasing N₂O emissions from light-duty vehicles is expected to continue as the result of increasingly stringent emission standards for NO_x. Long lifetime catalysts and reduced traffic congestion will also result in decreased N₂O emissions.

1. EXECUTIVE SUMMARY

Background. Assembly Bill 1493 (Pavley, 2002) required the California Air Resources Board (ARB) to develop greenhouse gas standards for vehicles, applicable to model year 2009 and beyond. This bill further required ARB to develop and adopt, by January 1, 2005, regulations that achieve the maximum feasible reduction of climate change species, including nitrous oxide (N₂O), emitted by light-duty vehicles. Nitrous oxide is important not only as a greenhouse gas but as the major natural source of nitrogen oxide in the stratosphere, where it is transported due to its long tropospheric lifetime of about 150 years. Based on weight and a 100-year period, N₂O is a greenhouse gas about 300 times more powerful than carbon dioxide. Compared to criteria pollutant tailpipe emissions, relatively few data were available for N₂O emission factors prior to the present study.

Methods. FTIR spectroscopy was used to determine nitrous oxide concentrations in dilute exhaust samples collected from vehicles tested at ARB's Haagen-Smit Laboratory. During the course of this project, we conducted more than 400 dynamometer experiments for 134 light-duty vehicles, including passenger cars (PC) and light-duty trucks (LDT), using three different driving cycles. A total of 161 real-time data collection experiments were part of this study in which, in addition to exhaust species concentrations, we collected exhaust and catalyst temperature data, fuel sulfur content, and air-to-fuel ratio data. For a limited number of vehicles, different catalyst configurations were also part of our testing program, including tests on vehicles with new, in-use, and empty catalysts. The sample of vehicles used in this work was a fraction of the fleet tested as part of the last two California's vehicle surveillance programs (VSP 16 and 17).

Results. Type of vehicle, driving cycle (driving conditions), applicable emissions standard, and catalyst temperature were the most important factors determining N₂O emissions from gasoline powered light-duty vehicles. LDT exhibited higher N₂O emission than PC; vehicles tested under the Urban Dynamometer Driving Schedule (UDDS) – or light-duty vehicle FTP – yielded higher N₂O emissions than vehicles tested under the Unified Cycle (UC); and TIER0 vehicles exhibited higher emission than low emission vehicles. Although it cannot be quantitatively determined using data from in-use vehicle testing programs, due to the presence of uncontrollable confounding factors and the lack of an appropriate range of values (not enough low-mileage or high-mileage test vehicles), a correlation between odometer readings (a proxy for catalyst age in most cases) and N₂O emissions can be found.

High catalyst temperatures (> 650 °C) were associated with lower N₂O emission factors and real-time N₂O emission patterns were closely related to catalyst temperatures. Catalyst temperatures below 120 °C are not adequate for NO reduction. Hence, N₂O production is very limited under these conditions. N₂O catalytic formation is enhanced between 120 and 550 °C. Catalyst temperatures above 650 °C generate optimal conditions for the conversion of NO to N₂, resulting in negligible production of N₂O.

Overall tailpipe N₂O/NO_x emissions ratios and overall tailpipe NO_x emissions can be used to roughly estimate N₂O emission factors for fleets that are similar in composition to the fleet for which the ratios were measured. Similarly, N₂O/NO_x emissions ratios can be used for emissions forecasting and backcasting as long as they are applied to fleets that are equivalent, in terms of

their emission standards, to the fleet for which the ratios were measured. It is important to note these tailpipe emissions ratios cannot be used as a measure of catalyst efficiency or a proxy for the catalyst's ability to reduce nitrogen oxides without producing significant quantities of N₂O.

The median emissions factor for all the tests we conducted was 14 mg km⁻¹ and the mean emissions factor was 20 mg km⁻¹ (N = 264; σ = 22). Table 1.1 summarizes the overall N₂O emission factors for the tested fleet.

Table 1.1. Overall N₂O emission factors (mg km⁻¹).

Parameter	Vehicle characteristic ¹	Number of vehicles tested	Number of tests	95% Confidence interval
Certification standard	Non-LEV - TIER0 ²	41	86	30 ± 6
Certification standard	Non-LEV - TIER1 ²	30	65	20 ± 5
Certification standard	TLEV	20	38	17 ± 4
Certification standard	LEV	39	64	12 ± 3
Certification standard	ULEV	4	5	3 ± 2
Test cycle	FTP-UDDS	114	138	23 ± 4
Test cycle	UC	106	126	18 ± 3
Vehicle class	LDT	48	100	26 ± 6
Vehicle class	PC	86	164	17 ± 2

¹ Details about model years and NO_x certification standards are provided in the body of the report (tables 2.2 and 3.2).

² Refers to federal standards (see Section 2.6)

Conclusions. The N₂O emission factors reported here are lower than those reported in previous research since the fleet we tested included recent model-year vehicles equipped with efficient emission control technologies that resulted in lower N₂O emissions. This pattern of decreasing N₂O emissions from light-duty vehicles will continue as the result of increasingly stringent emission standards for NO_x.

Mobile source nitrous oxide emissions are a consequence of the introduction of emission control technologies aimed at reducing criteria pollutants (specifically NO_x). Although modern catalysts and stringent emission standards have resulted in decreased N₂O emissions, the catalytic formation of this species provides an example of an environmental protection program that while addressing one problem is also causing a negative impact. This demonstrates the importance of a comprehensive analysis when implementing technical approaches to reducing pollutant emissions. Long lifetime catalysts will result in decreased N₂O emissions since, similar to other exhaust species, these emissions depend on the overall performance of the catalytic converter. Reducing traffic congestion would also result in lower N₂O emissions since hot stabilized operating conditions (sustained high catalyst temperatures and no extreme accelerations) result in improved catalyst performance.

2. INTRODUCTION, BACKGROUND, AND OBJECTIVES

Assembly Bill 1493 (Pavley, 2002) required the California Air Resources Board to develop greenhouse gas standards for vehicles, applicable to model year 2009 and beyond. This bill further required ARB to develop and adopt, by January 1, 2005, regulations that achieve the maximum feasible reduction of climate change species (CCS) emitted by passenger vehicles and light-duty trucks. This regulation is based, in part, on an emissions inventory developed by ARB, as well as on the assessment of cost-effective technological benefits and possible alternative control strategies derived from an understanding of the factors that affect such an inventory.

This landmark piece of legislation (the first worldwide to consider curbing climate change species from mobile sources) was motivated, in part, by the fact that in the past decade while various air pollutant emissions decreased in the United States, nitrous oxide emissions increased by 25% (USEPA, 1998). It is well documented that emissions control technologies employed on highway vehicles in the United States (e.g., catalytic converter) lowered carbon monoxide (CO), nitrogen oxides (NO_x), non-methane volatile organic compounds (NMVOC), total hydrocarbons (THC), and methane (CH₄) emissions, but resulted in higher N₂O and carbon dioxide (CO₂) emission rates due to catalytic conversion to these species.

Although mobile sources are among the largest anthropogenic sources of N₂O emissions in the United States, compared to criteria pollutants relatively few data are available to estimate emission factors for nitrous oxide from motor vehicles. Estimates of the contribution of N₂O emissions from mobile sources to the inventory of U.S. greenhouse gas emissions, in terms of equivalent CO₂ emissions, range between 0.5% and 3% (Michaels, 1998).

2.1. Previous Research

Early studies of N₂O emissions from vehicle exhaust date back to the 1970s (Bradow and Stump, 1977; Urban and Garbe, 1979; Cadle et al., 1979; Smith and Carey, 1982). More recent studies of N₂O emissions from vehicle exhaust have included chassis dynamometer testing (Jobson et al., 1994; Laurikko and Aakko, 1995; Cadle et al., 1997; Odaka et al., 1998; Michaels et al., 1998), tunnel studies (Berges et al., 1993; Sjödin et al., 1995), engine testing (Pringent and De Soete, 1989), and studies using catalyst test beds (Koike et al., 1999). Several of these studies reported no measurable differences between N₂O concentrations in engine-out exhaust and the background (ambient air) levels of approximately 0.3 ppm. However, once exhaust gases pass through a catalytic converter, N₂O emissions increase significantly, indicating that N₂O is formed during the catalytic reduction of nitric oxide (NO) to molecular nitrogen (Ballantyne et al., 1994).

Dasch (1992) conducted nitrous oxide measurements on nine vehicles and combined these values with literature data from additional 32 vehicles to estimate typical N₂O emission factors. According to this study, emissions averaged 2.2 mg km⁻¹ from non-catalysts cars, 18 mg km⁻¹ from vehicles with oxidation catalysts, 38 mg km⁻¹ from vehicles with dual-bed catalysts, and 28 mg km⁻¹ from vehicles with three-way catalyst (TWC). Koike et al. (1999) determined concentrations of nitrous oxide tend to decrease as the quantities of precious metals carried by the catalyst decrease, confirming the role of these catalytic species in the formation of N₂O. In a

similar study, Odaka et al. (1998) documented how catalyst deactivation from aging resulted in increased emissions of nitrous oxide. Michaels (1998) reported average emission factors for Tier 0-certified passenger vehicles were close to twice the average emission factors for Tier 1-certified passenger vehicles.

The U.S. default values for N₂O emission factors from passenger cars in the revised 1996 Intergovernmental Panel on Climate Change (IPCC) guidelines were based on three studies that tested five cars using European rather than U.S. test protocols. Emission factors for gasoline vehicles other than passenger cars were scaled from those for passenger cars with the same control technologies, based on their relative fuel economy. This scaling was supported by limited data showing that light-duty trucks emit more N₂O than passenger cars with equivalent control technology. The use of fuel-consumption ratios to determine emission factors is considered a temporary measure, to be replaced as soon as additional testing data are available (IPCC, 1997).

To characterize the entire U.S. fleet, the U.S. Environmental Protection Agency (USEPA, 1998) estimated N₂O emission factors based on tests from 50 vehicles and their relative fuel economy. Using the same 37 vehicles analyzed as part of our pilot study (see Chapter 4), ARB estimated nitrous oxide emission factors for the California fleet based on the correlation between N₂O and nitrogen oxides emissions. The IPCC has also calculated emission inventories for N₂O (IPCC, 1997; USEPA, 1998) and is presently reassessing those inventories (Gillenwater, 2004). To supplement these ARB, USEPA and IPCC estimates, Lipman and Delucchi (2002) recently developed an extensive database, based on published data, to estimate emission factors for N₂O from conventional vehicles.

Becker et al. (2000) compared emissions measured in a German tunnel to dynamometer measurements for a small fleet of recent model-year vehicles, finding consistent results between these two approaches and an average emissions factor of $11 \pm 5 \text{ mg km}^{-1}$ for the dynamometer-tested fleet. Durbin et al. (2001) characterized the exhaust emissions of a fleet of 10 alternative-fueled vehicles. In addition to the standard measurements of regulated pollutants, the primary focus of this work was on the measurement of ammonia (NH₃) and N₂O emissions using Fourier transform infrared (FTIR) spectroscopy. N₂O emissions averaged 14 mg km^{-1} with a range between 1 and 48 mg km^{-1} .

Behrentz et al. (2004) used dynamometer testing in conjunction with high-resolution FTIR spectroscopy to measure exhaust emissions of nitrous oxide from a fleet of 37 light-duty vehicles (LDV) including passenger cars, sport utility vehicles (SUV), and light-duty trucks (see Chapter 4). Huai et al. (2004) tested 60 vehicles ranging from non-catalyst to super ultra low-emission vehicles (SULEV) using conventional driving cycles such as the federal test procedure (FTP) as well as hot running and more aggressive driving cycles. Increases in fuel sulfur content from 30 to 330 ppmw were found to increase N₂O emissions by almost 4 times.

Figure 2.1 summarizes the results reported in previous comparable research.

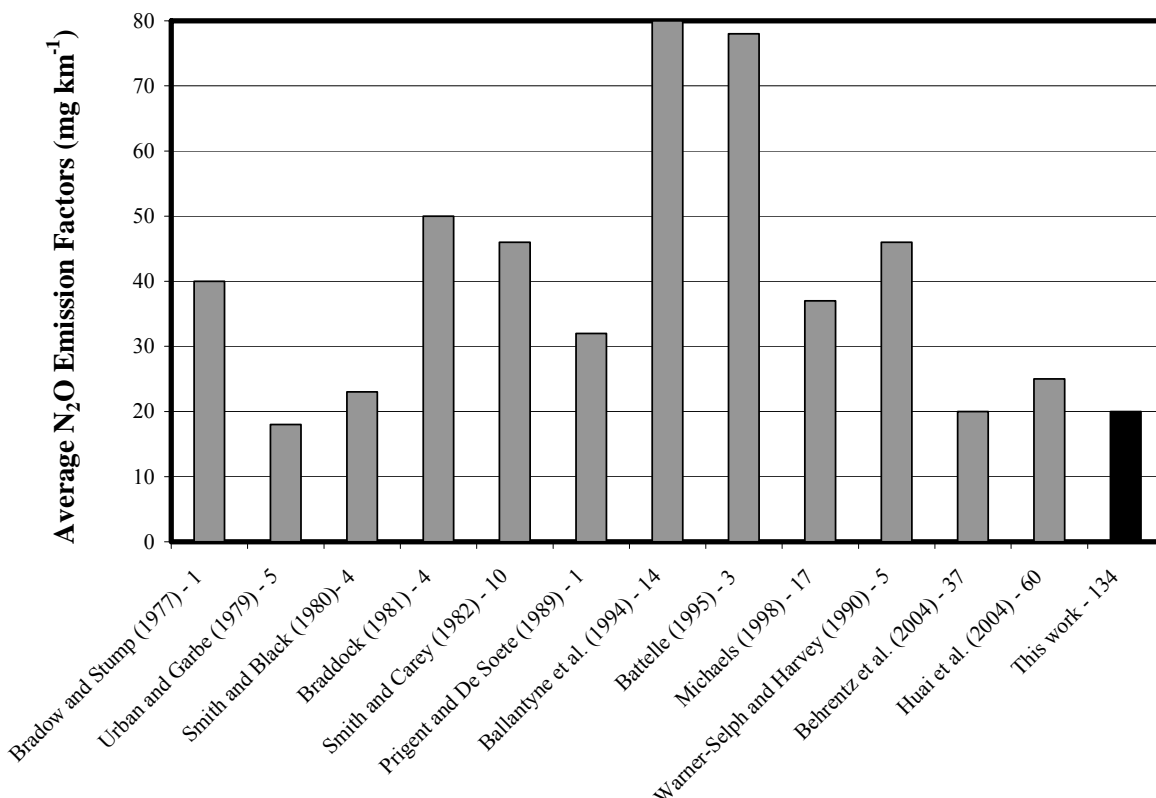


Figure 2.1. Nitrous oxide emission factors reported in previous research (the number next to the reference represents the number of vehicles tested).

2.2. Background

Climate change is driven by changes in the atmospheric concentrations of a number of active gases and aerosols. There is evidence human activities have affected the concentrations, distributions, and life cycles of these gases (IPCC, 1997). Naturally occurring greenhouse gases include water vapor, carbon dioxide, methane, nitrous oxide, and ozone.

Nitrous oxide (dinitrogen monoxide) is important not only as a greenhouse gas but as the major natural source of NO_x (NO + NO₂) in the stratosphere, where it is transported due to its long tropospheric lifetime (Crutzen, 1970) of about 150 years (Finlayson-Pitts and Pitts, 1999).

Nitrous oxide (CAS # 10024-97-2) is a colorless gas with a slight sweet odor and taste. It has a boiling point of -88°C and its specific gravity is 1.22. N₂O has a vapor density of 1.5 (at 20°C) and a vapor pressure of 754 psia (at the same temperature).

Also known as “laughing gas,” N₂O is continuously emitted to and removed from the atmosphere by natural processes and its major sources include nitrification and denitrification in soils and aquatic systems. Anthropogenic activities, however, can cause additional quantities of this and other greenhouse gases to be emitted-to or sequestered from the atmosphere, thereby changing their global average atmospheric concentrations. Anthropogenic sources of N₂O

emissions include agricultural soils; fossil fuel combustion, especially from mobile sources; adipic (nylon) and nitric acid production; wastewater treatment and waste combustion; and biomass burning (Bouwman and Taylor, 1996). The global budget for N₂O is shown in Table 2.1.

The atmospheric concentration of nitrous oxide in 1994 was about 312 parts per billion by volume (ppbv), while pre-industrial concentrations were roughly 275 ppbv (Seinfeld and Pandis, 1998). The majority of this increase has occurred after the pre-industrial period and is most likely due to anthropogenic activities (IPCC, 1997).

Table 2.1. Estimated annual global N₂O budget
(Adapted from Bouwman and Taylor, 1996)

Source	Emissions (Tg of N ₂ O year ⁻¹)
Soils under natural vegetation and grasslands	5.7
Oceans	3.6
Arable lands	1
Nitrogen fertilizer use	1
Animal wastes	1
Industry	0.5
Post-clearing enhanced soil flux	0.4
Mobile sources and fossil fuel combustion	0.3
Biomass burning	0.1
Agricultural waste burning	0.1
Bio-fuel combustion	0.1
Total sources	13.8

Motor vehicle usage is increasing all over the world, including in the United States. Since the 1970s, the number of highway vehicles registered in the U.S. has increased faster than the overall population, according to the Federal Highway Administration (FHWA, 1997). Likewise, the number of miles driven—up 15 percent since 1990—and gallons of gasoline consumed each year in the United States have increased relatively steadily since the 1980s, according to the Energy Information Administration (EIA, 1997). New vehicles are now equipped with advanced emission controls designed to reduce emissions of criteria pollutants. However, as mentioned before, these technologies have had a negative impact on the emissions of other non-regulated species, such as nitrous oxide.

2.3. The Catalytic Converter

Controlling engine-out emissions using catalytic converters dates back to the 1970s when the oxidation catalyst was introduced by the auto manufacturers. These devices significantly reduced tailpipe emissions by oxidizing CO and hydrocarbons produced by the incomplete combustion of fuel in the vehicle's engine. Oxidation catalyst used precious metals such as

platinum and palladium as catalytic species. Later developments in the catalytic converter technology led to the introduction of the TWC, which in addition to oxidizing CO and THC, it reduced nitrogen oxides present in the engine-out gases by adding rhodium to the mixture of precious metals.

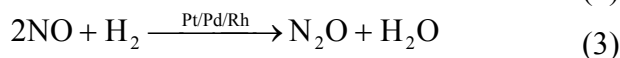
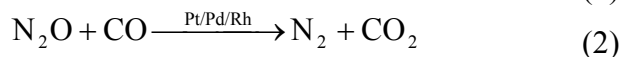
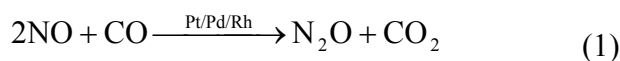
The main components of a modern TWC are depicted in Figure 2.2: 1) The oxygen sensor is a device capable of measuring oxygen concentrations in the exhaust that is used by the vehicle feedback system to adjust, as necessary, the air-to-fuel ratio to ensure stoichiometric conditions in the combustion chamber in order to optimize the catalyst performance. 2) The honeycomb precious metal-coated ceramic structure exposes the maximum surface area to the exhaust stream while minimizing the pressure drop. This is the place where the catalytic oxidation and reduction reactions take place. 3) A stainless steel mesh surrounds the ceramic structure for additional robustness and heat insulation. 4) The stainless steel shell houses the components and protects the active elements of the catalytic converter.

2.4. Formation of Nitrous Oxide

The formation of N₂O during coal and oil combustion is linked in the literature with fuel nitrogen (Lanier and Robinson, 1986). Due to their higher nitrogen content, coal and oil burning are believed to emit more N₂O than natural gas or gasoline.

A potential source of N₂O is the heterogeneous oxidation of nitrous acid (HONO) on surfaces (Wiesen et al., 1995; Pires and Rossi, 1997), which has been observed to form N₂O. More than 15 years ago, Muzio and Kramlich (1988) suggested this effect could be responsible for the observation of significant amounts of nitrous oxide in automobile exhaust as an artifact of sampling; however, we are not aware of any confirmation of this hypothesis by subsequent research.

Nitrous oxide forms as an intermediate during the catalytic reduction of nitric oxide to molecular nitrogen (N₂). The reactions involved, which take place between species adsorbed on the surface of the catalyst, are believed to be the following (Weiss and Craig, 1976; Cho et al., 1989):



At high temperatures, NO is directly reduced to N₂ over the catalyst. However, at lower temperatures, N₂O is an intermediate product, as shown in reactions (1) and (3). There is evidence from continuous FTIR spectroscopy measurements made on vehicular exhaust that N₂O is formed during catalyst warm-up, but that formation tends to cease after the catalyst is in full operation (See Section 5.3.6). For the reactions above to take place it is required to have both, the support medium (catalyst surface) and the catalytic substances (precious metals). This is the reason why vehicles without catalytic converters do not emit nitrous oxide (see Section 5.3.7). Different precious metals as well as their quantities and proportions within a catalyst produce

different efficiencies in terms of their N₂O production. As discussed in Section 6.3.1, catalyst type is among the variables that significantly affect N₂O emissions from LDVs.

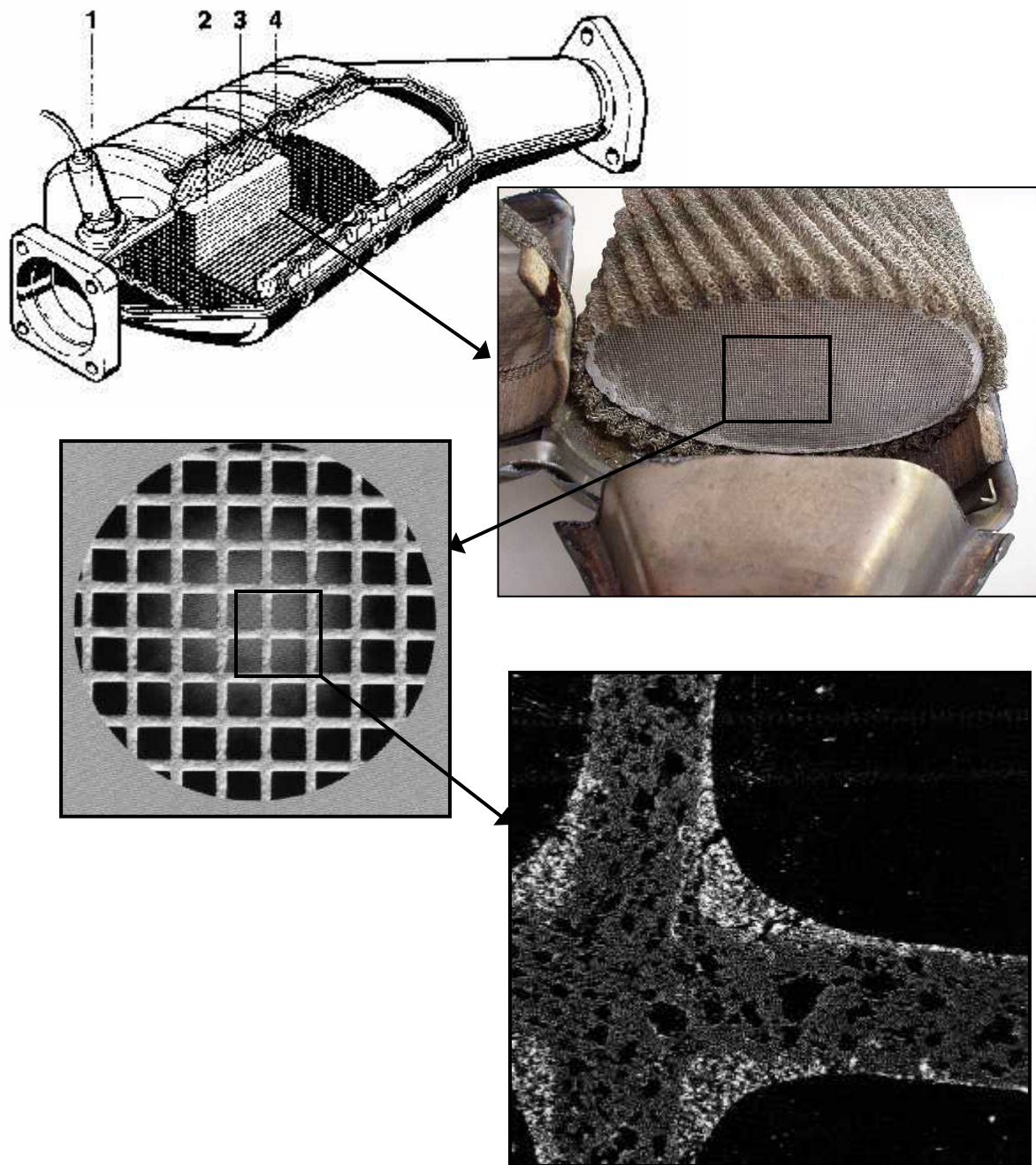


Figure 2.2. Components of the three-way catalytic converter.
(Adapted from Osses, 2004).

2.5. FTIR Spectroscopy

During our study, FTIR spectroscopy was used to determine nitrous oxide concentrations in dilute exhaust samples. Similar analytical techniques have been used in a wide range of air pollution-related studies in both ambient air and environmental chambers (Graham et al., 1977, 1978; Tuazon et al., 1978; Doyle et al., 1979; Tuazon et al., 1980, 1981, 1983; Pitts et al., 1983; Biermann et al., 1988).

Long optical path FTIR spectroscopy, in particular, led to the first unambiguous spectroscopic identification of nitric acid, formaldehyde and formic acid in the polluted troposphere (Tuazon et al., 1981) and contributed importantly to the elucidation of gas-phase chemistry relevant to photochemical smog formation and to stratospheric chemistry (Atkinson et al., 1986, 1987), as well as our understanding of trace nitrogenous species in urban atmospheres (Pitts et al., 1983; Winer, 1985).

FTIR spectroscopy has been employed in several studies specifically focused on nitrous oxide measurements. Galle et al. (1994) demonstrated the feasibility of FTIR spectroscopy for on-line real-time analysis of N₂O using parallel measurements between FTIR and gas chromatography techniques in a conventional field chamber.

Griffith and Galle (2000) assessed the feasibility of dual-beam FTIR spectroscopy and a sampling system for simultaneous measurements of fluxes of several trace gases, including nitrous oxide. The experimental technique used in this study exhibited a precision for N₂O measurements of around 0.5 ppbv for 20-minute measurements.

Griffith et al. (2002), proved the reliability of an FTIR system to measure fluxes of trace gases, including N₂O, between agricultural fields and the atmosphere. The system operated continuously and automatically for 19 days without any loss of data or degradation in data quality. Eklund and LaCosse (1998) demonstrated the FTIR measurement is a successful approach for the simultaneous collection of large amounts of ambient concentrations data for trace gases. In this study, the target compounds of interest included nitrous oxide, ammonia and methane.

2.6. Exhaust Emission Standards

In 1970, the U.S. Congress passed the Clean Air Act, which called for the first tailpipe emission standards. These federal standards were into effect in 1975. In 1977, Congress amended the Clean Air Act and tightened the standards in two steps, between 1977 and 1979, and after 1981 (Tier 0). In 1994 more stringent emission standards (Tier 1) were introduced, representing a 40% percent reduction from the Tier 0 standards.

The low emission vehicle (LEV) program in California has also resulted in specific exhaust emission standards including transitional low emission vehicle (TLEV) standards, which are more stringent than Tier 1 standards for THC; LEV standards, more stringent than TLEV standards for both THC and NO_x; ultra low emission vehicle (ULEV) standards, more stringent than LEV standards for THC; SULEV standards, even more stringent than ULEV for both THC and NO_x; and finally the zero emission vehicle (ZEV) standards, permitting no emissions. Table 2.2 summarizes selected federal and California emission standards for light-duty vehicles.

Appendix A contains a comprehensive list of California emission standards including information about specific model years.

Table 2.2. Selected Federal and California certification exhaust emission standards for light-duty vehicles.

		Certification for first five years / 50,000 miles			
		NMHC	NMOG	CO	NO _x
PC	Tier 0	0.39	-	7.0	0.4
	Tier 1	0.25	-	3.4	0.4
	TLEV	-	0.125	3.4	0.4
	LEV	-	0.075	3.4	0.2
	ULEV	-	0.040	1.7	0.2
	ZEV	0.00	0.000	0.0	0.0
LDT1	Tier 0	0.39	-	9.0	0.4
	Tier 1	0.25	-	3.4	0.4
	TLEV	-	0.125	3.4	0.4
	LEV	-	0.075	3.4	0.2
	ULEV	-	0.040	1.7	0.2
	ZEV	0.00	0.000	0.0	0.0
LDT2	Tier 0	0.50	-	9.0	1.0
	Tier 1	0.32	-	4.4	0.7
	TLEV	-	0.160	4.4	0.7
	LEV	-	0.100	4.4	0.4
	ULEV	-	0.050	2.2	0.4
	ZEV	0.00	0.000	0.0	0.0

All values in g mi⁻¹ and applicable to the federal test procedure. LDT1: light-duty truck up through 3,750 lbs loaded vehicle weight. LDT2: light-duty truck greater than 3,750 lbs loaded vehicle weight. A light-duty truck is any motor vehicle rated at 8,500 pounds (gross vehicle weight rating) or less which has a vehicle curb weight of 6,000 pounds or less and which has a basic vehicle frontal area of 45 square feet or less, which is (1) Designed primarily for purposes of transportation of property or is a derivation of such a vehicle, or (2) Designed primarily for transportation of persons and has a capacity of more than 12 persons, or (3) Available with special features enabling off-street or off-highway operation and use. Passenger car is any motor vehicle designed primarily for transportation of persons and having a design capacity of 12 persons or less.

Source: Federal and California Exhaust and Evaporative Emission Standards for Light-Duty Vehicles and Light-Duty Trucks. USEPA 2000 (EPA420-B-00-001).

2.7. Statement of the Problem

Mobile sources emit greenhouse gases other than CO₂, including CH₄ and N₂O. As with combustion in stationary sources, N₂O emissions are closely related to fuel characteristics, air-fuel mixtures, and combustion temperatures, as well as the nature and operating characteristics of pollution control equipment. Nitrous oxide, in particular, can be formed by the catalytic processes used to control NO_x and CO emissions. Research has shown N₂O emissions from vehicles with catalytic converters are greater than those without emission controls, and that vehicles with aged catalysts emit more than new ones (Ballantyne et al., 1994; Barton and Simpson, 1994).

However, compared to regulated tailpipe emissions, relatively few data are available to estimate emission factors for nitrous oxide, in part because N₂O is not a criteria pollutant and measurements of this species in automobile exhaust have not been routinely collected. Further testing is needed to reduce the uncertainty in nitrous oxide emission factors for all classes of vehicles, using realistic driving regimes, appropriate environmental conditions, and representative fuels. Additional testing is also required to better understand the process of N₂O formation in the catalyst and to quantify the effect of the different variables that may affect the emissions of this powerful climate change species.

2.8. Objectives and Hypotheses

2.8.1. *Overall Objectives*

The overall goal of this research was to measure exhaust emissions of nitrous oxide to more accurately characterize California motor vehicle emissions of N₂O, and to investigate the effects of catalyst composition and aging on these emissions. The emphasis of the study was on characterizing and quantifying the important variables, related to driving conditions and catalyst performance, that affect N₂O emissions from gasoline-powered light-duty vehicles.

2.8.2. *Specific Objectives*

The specific objectives of this project included developing and refining the required FTIR analytical methods for determination of nitrous oxide in dilute exhaust, recruiting an appropriate population of test vehicles, to conduct matrices of N₂O exhaust emissions measurements, and estimating nitrous oxide emission factors representative of the California LDV fleet.

2.8.3. *Hypotheses*

The underlying hypothesis of our research work was that it is possible to characterize accurately the N₂O emissions from automobiles in California. We also worked with the hypotheses that it is possible to determine which catalyst configurations and operating conditions produce lower N₂O emissions, and that it is possible to determine specific correlations between the emissions of N₂O and other vehicle exhaust-related species.

3. EXPERIMENTAL METHODS AND INSTRUMENTATION

During our study we collected and analyzed real-time and integrated dilute exhaust samples from vehicles tested at ARB's Haagen-Smit Laboratory (HSL) in El Monte, California using a wide variety of instruments and equipment as well as complex experimental methods that are explained in this chapter.

3.1. Summary of Approach

During the course of this project, we conducted more than 400 experiments on 134 light-duty vehicles, including passenger cars and light-duty trucks, using three different driving cycles. 161 real-time data collection experiments were part of this study, in which in addition to exhaust species concentrations we collected exhaust and catalyst temperature data, fuel sulfur content, and air-to-fuel ratio data. For a limited number of vehicles, different catalyst configurations were also part of our testing program, including tests on vehicles with new, in-use, and empty catalysts.

The sample of vehicles used in this work was a fraction of the fleet tested as part of the last two ARB's vehicle surveillance programs (VSPs), including cars from 18 different manufacturers varying from Tier 0 to ULEV in their emission standards, from 1.0 to 5.4 liters in their engine's displacement, from 1982 to 2002 in their model-year, and from 3,000 to 522,000 km in their odometer readings.

The organization of this document reflects the main components of our project, which can be divided in three parts: pilot study (Chapter 4), real-time data analysis (Chapter 5), and comprehensive analyses of the integrated samples database that was built with the results of our testing program (Chapter 6), which also includes the calculation of representative nitrous oxide emission factors for California vehicles and a discussion about the most important variables affecting such emissions.

Figure 3.1 is a schematic of our summary of approach and Figure 3.2 depicts the experimental system used for the majority of our tests.

3.2. Recruitment of Vehicles

The first step of our program was acquiring a proper sample of light-duty vehicles (PC and LDT) to conduct our tests. These vehicles were a subset of the fleet tested as part as ARB's 16th and 17th vehicle surveillance programs, in which a sample of vehicles representative of the California fleet were tested for various purposes. During these type of programs, based on department of motor vehicles registration data, a number of target vehicles is assigned to specific model years and vehicle types to be then randomly selected (using VIN patterns) from within a 40-kilometer radius of ARB's HSL. The primary objective of these programs is to determine a fleet "snapshot" of baseline emissions for the mobile source inventory (ARB, 2003).

As mentioned above, prior to the random selection, target vehicles are identified considering current characteristics of the in-use light-duty fleet, including variables such as vehicle type, model year, and emissions control technology. Table 3.1 summarizes current control technology assignments for California gasoline passenger cars and light-duty trucks and

Figure 3.3 depicts the vehicle miles traveled (VMT) in California by vehicle age and vehicle type.

We tested a total of 134 light-duty vehicles including PC, SUV, and LDT. For all our comparisons and analyses, consistent with current emission standards, SUV, LDT1, and LDT2 were considered as part of the same category (LDT) and we did not differentiate between them. Table 3.2 summarizes the characteristics of the vehicles tested in this project.

3.3. Vehicle Testing

Vehicle testing involved vehicle preparation, placing the vehicles on the dynamometer unit, performing the appropriate driving cycles on the vehicles, and collecting and analyzing their exhaust emissions.

3.3.1. *Vehicle Preparation*

Vehicle preparation involved driving the vehicle on the dynamometer at an 80-kilometer per hour steady-state speed for 10 minutes. Exhaust emission samples were not collected during vehicle preparation. Vehicles were prepared the day before testing and placed in a temperature controlled area (cold soak room) for a minimum of 12 hours. The temperature in the cold soak room was kept between 20 and 30 °C. The following day (test day) the vehicle was pushed (engine not started) out of the cold soak room and placed onto the dynamometer for testing (see Figures 3.4 and 3.5).

3.3.2. *Vehicle Setup*

After the vehicles were moved into the testing cells, they were carefully positioned onto the dynamometer roller to reduce side-to-side movement during testing. The dynamometer shells were used to perpendicularly align, with the centerline of the dynamometer roller, the drive wheels onto the roller. After placement, the non-drive wheels of the vehicle were secured using chocks and ties. If the vehicle was front wheel drive, the front wheels were placed on the dynamometer roller and the rear wheels were secured. If the vehicle was rear wheel drive, the rear wheels were placed on the dynamometer roller and the front wheels were secured (see Figure 3.6). The tire pressure of the drive wheels was adjusted to meet automotive manufacturer specifications.

Once the vehicle was secured in place, the engine's compartment hood was opened and a fan placed pointing to the radiator to provide cooling air (see Figure 3.6). A flat screen monitor was placed outside the front windshield in front of the driver seat (see Figure 3.7). This monitor was attached to the control computer to provide the drive trace (see below) and the driver was supposed to follow it during the test. The remote mixing tee (RMT), as part of the constant volume sampler (CVS) collection system (see below), was attached to the vehicle's exhaust tailpipe immediately before the beginning of exhaust emissions tests (see Figure 3.8). A standard exhaust tip was attached to vehicles equipped with single exhaust tailpipes. A stainless steel exhaust tip was slipped over the tailpipe and clamped in place using a silicone-tubing sleeve to make an airtight seal. The tailpipe assembly was then clamped to the transfer tube connector to route the exhaust emissions to the RMT.

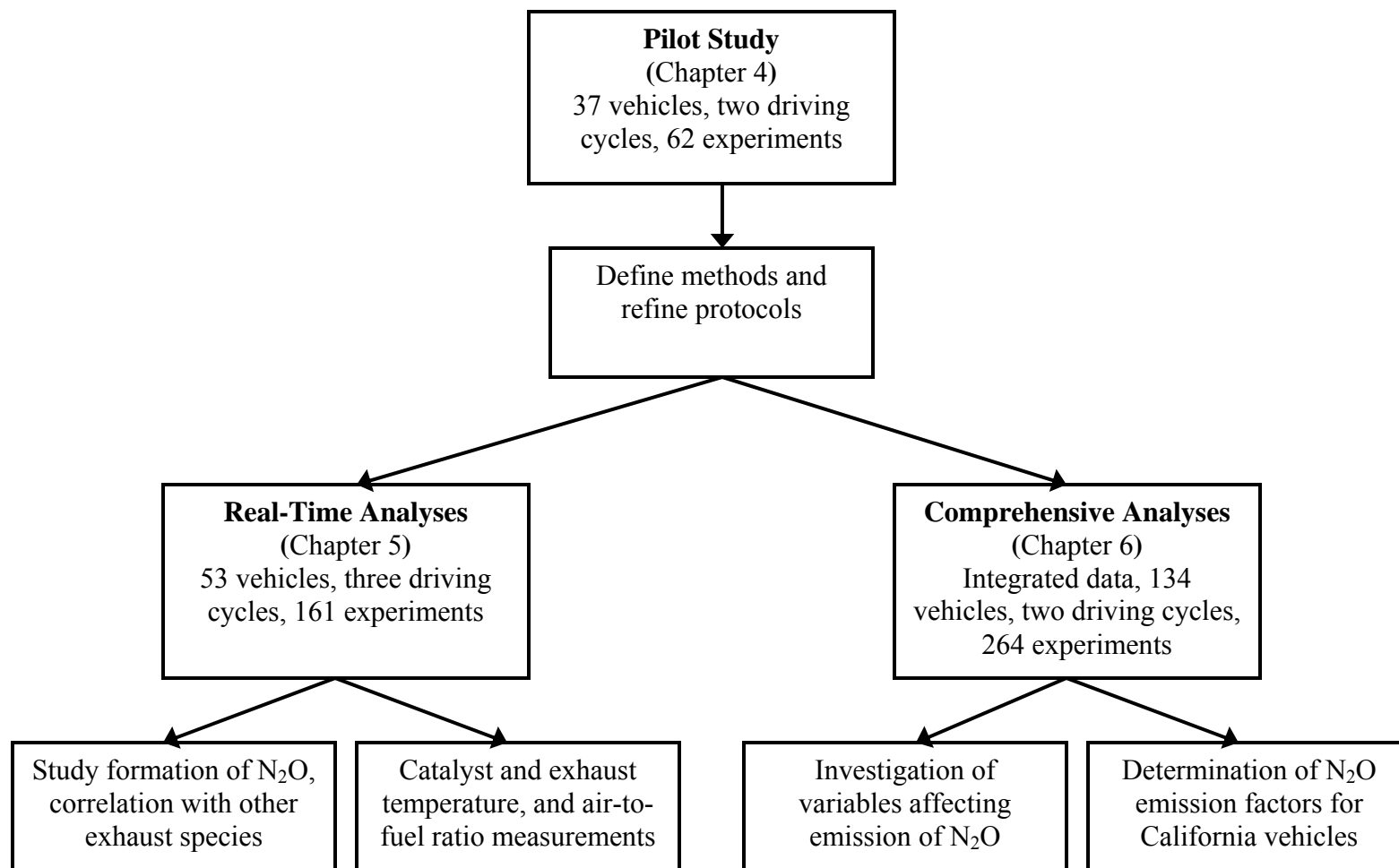


Figure 3.1. Schematic of summary of approach.

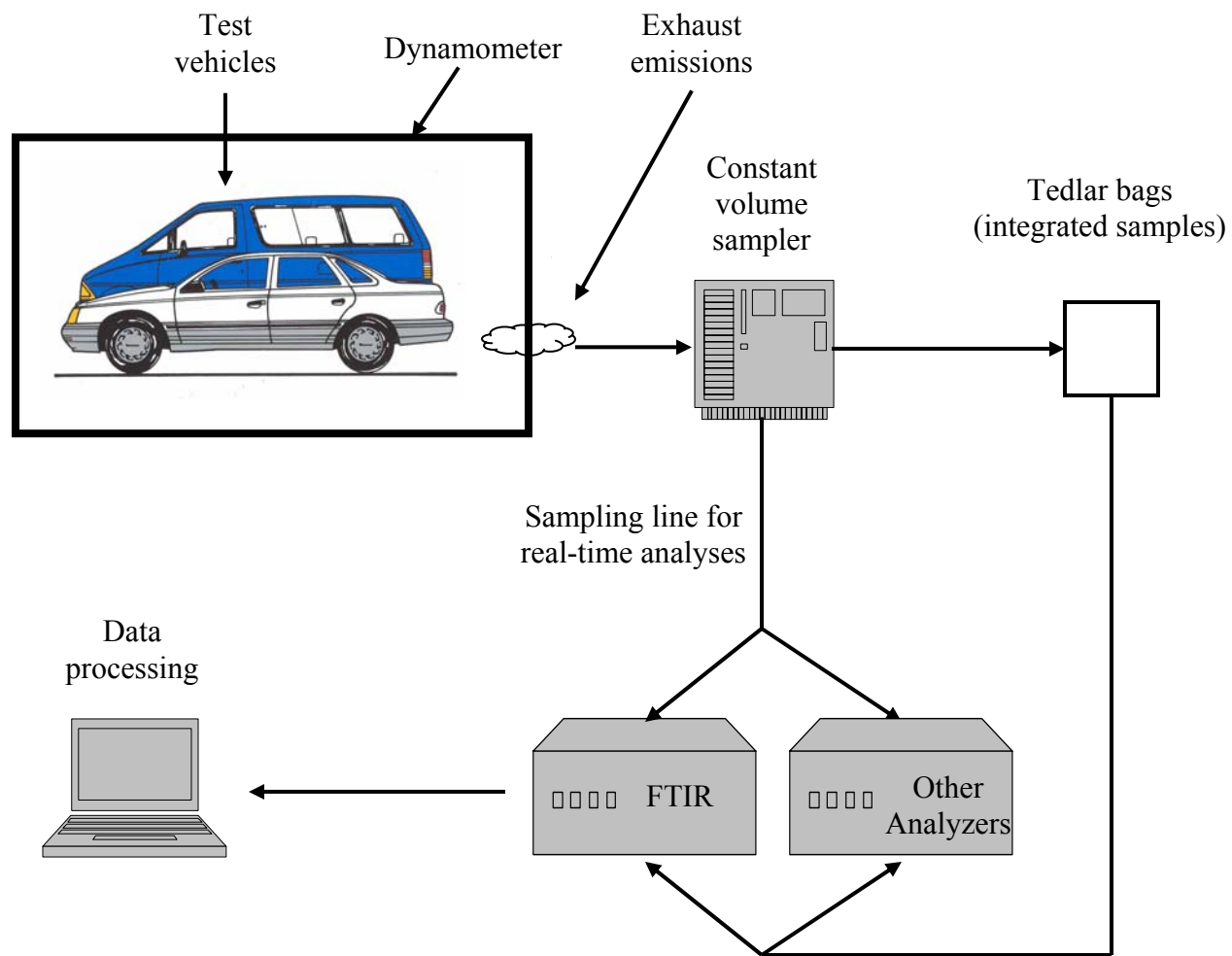


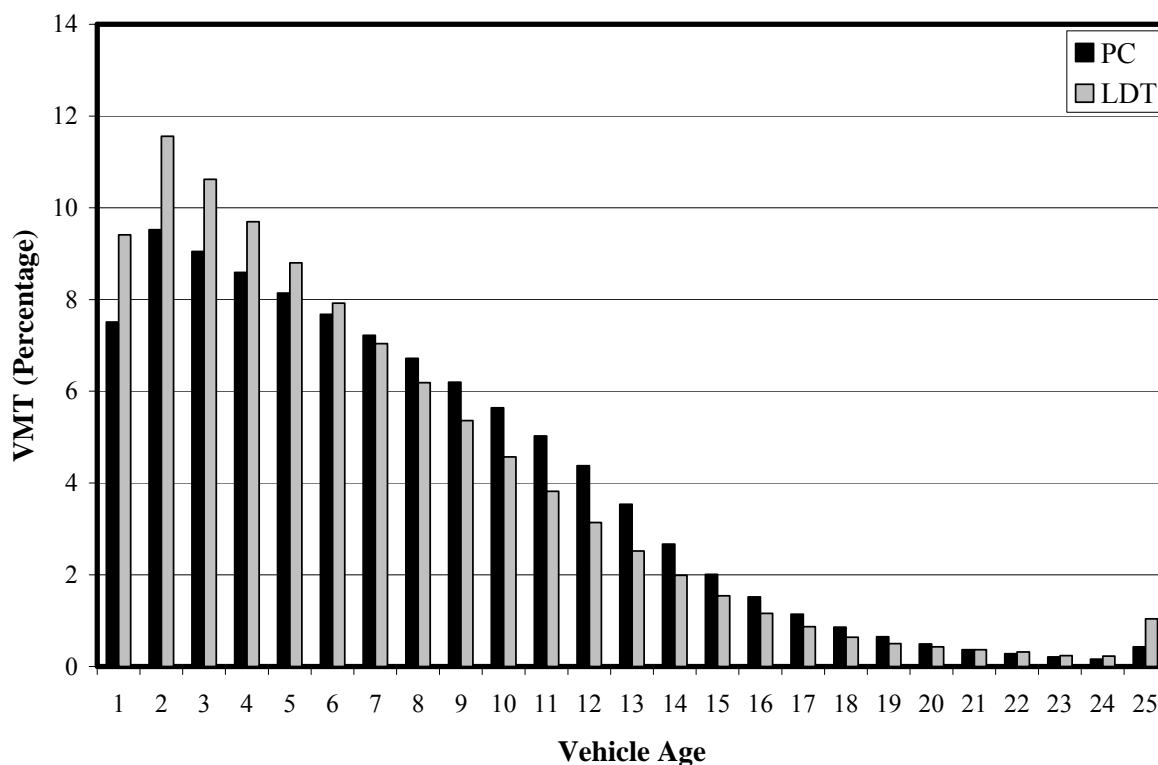
Figure 3.2. Schematic representation of experimental system used for emissions testing.

Table 3.1. Control technology assignments for California gasoline passenger cars and light-duty trucks (percent of VMT).

Model years	Non-catalyst	Oxidation	Tier 0	Tier 1	LEV
1973 - 1974	100	-	-	-	-
1975 - 1979	-	100	-	-	-
1980 - 1981	-	15	85	-	-
1982	-	14	86	-	-
1983	-	12	88	-	-
1984 - 1991	-	-	100	-	-
1992	-	-	60	40	-
1993	-	-	20	80	-
1994	-	-	-	90	10
1995	-	-	-	85	15
1996 - 2000	-	-	-	80	20

- Not applicable

Source: USEPA (2002)

**Figure 3.3.** Vehicle miles traveled in California by vehicle age and type.

Adapted from USEPA (2002).

Table 3.2. Characteristics of the test vehicles

Number	Vehicle Code	Manufac.	Model	Engine's displacement (l)	Model year	Odometer (km)	Emissions Standard
1	PC	BMW	318i	1.8	1994	115,000	TIER1
2	LDT	Chrysler	Cherokee	4.0	1999	27,000	TLEV
3	LDT	Chrysler	Grand Caravan	3.3	1997	112,000	TLEV
4	LDT	Chrysler	Grand Caravan	3.0	1996	180,000	TIER0
5	LDT	Chrysler	Grand Caravan	3.3	2002	25,000	LEV
6	LDT	Chrysler	Grand Cherokee	4.0	1998	88,000	TLEV
7	LDT	Chrysler	Grand Cherokee	4.0	1998	137,000	TLEV
8	PC	Chrysler	Lebaron LE	3.0	1991	151,000	TIER0
9	PC	Chrysler	Neon	2.0	1995	97,000	TIER1
10	PC	Chrysler	Neon	2.0	1995	102,000	TIER1
11	PC	Chrysler	Neon	2.0	1998	122,000	TIER1
12	PC	Chrysler	PT Cruiser	2.4	2001	46,000	LEV
13	LDT	Chrysler	Ram 1500	5.2	1998	100,000	LEV
14	LDT	Chrysler	Ram 250	5.2	1985	251,000	TIER0
15	LDT	Chrysler	Towncountry	3.8	1996	224,000	TIER1
16	LDT	Chrysler	Voyager	3.0	1988	289,000	TIER0
17	PC	Ford	Capri GS	3.8	1986	109,000	TIER0
18	LDT	Ford	Econoline 150	5.8	1994	224,000	TLEV
19	LDT	Ford	Econoline 350	5.8	1994	299,000	TIER0
20	PC	Ford	Escort LX	1.9	1996	222,000	TIER1
21	LDT	Ford	Expedition XLT	5.3	1997	128,000	TIER1
22	LDT	Ford	Explorer EB	4.0	2001	158,000	LEV
23	LDT	Ford	Explorer XLS	4.0	2002	60,000	LEV
24	LDT	Ford	F-150	5.8	1991	110,000	TIER0
25	LDT	Ford	F-250 XL	4.9	1996	256,000	TIER1
26	LDT	Ford	Ranger	2.3	1995	254,000	TIER1
27	LDT	Ford	Ranger XL	3.0	1995	238,000	TIER1
28	LDT	Ford	Ranger XLT	4.0	1993	105,000	LEV
29	LDT	Ford	Ranger XLT	2.3	1997	112,000	TIER1
30	PC	Ford	Taurus GL	3.0	1994	83,000	TLEV
31	PC	Ford	Taurus LS	3.0	2001	3,000	LEV
32	PC	Ford	Taurus SE	3.0	1999	111,000	LEV
33	LDT	Ford	Villager GS	3.0	1993	197,000	TIER0
34	LDT	Ford	Windstar GL	3.8	1995	254,000	TIER1
35	LDT	Ford	Windstar VAN	3.8	2000	60,000	ULEV
36	LDT	GM	1500	5.0	1996	155,000	TIER1
37	PC	GM	6000 LE	2.8	1989	172,000	TIER0
38	LDT	GM	Blazer	2.8	1985	163,000	TIER0
39	PC	GM	Camaro	5.0	1989	276,000	TIER0
40	PC	GM	Camaro Z28	5.7	1996	169,000	TIER1
41	PC	GM	Caprice Classic	5.0	1992	113,000	TIER0
42	PC	GM	Caprice Classic	5.0	1983	207,000	TIER0
43	PC	GM	Cavalier	2.2	1998	100,000	TLEV
44	PC	GM	Cavalier	2.4	1998	134,000	TLEV
45	PC	GM	Cavalier Z27	2.4	1997	139,000	TLEV
46	PC	GM	Century	3.1	1997	91,000	TIER1

Table 3.2 (con't)

Number	Vehicle Code	Manufac.	Model	Engine's displacement (l)	Model year	Odometer (km)	Emissions Standard
47	PC	GM	Cutlass Supreme	2.8	1988	232,000	TIER0
48	PC	GM	Deville	4.9	1993	162,000	TIER0
49	PC	GM	Deville	4.9	1991	86,000	TIER0
50	PC	GM	Eldorado	4.6	1998	129,000	TIER1
51	PC	GM	Eldorado	4.1	1987	276,000	TIER0
52	PC	GM	Eldorado Biarritz	4.1	1986	103,000	TIER0
53	PC	GM	Grand Am	3.3	1992	142,000	TIER0
54	PC	GM	Grand AM-SE	3.1	1997	112,000	TIER1
55	PC	GM	Malibu LS	3.1	1998	81,000	TLEV
56	LDT	GM	S10	2.2	1995	179,000	TIER1
57	PC	GM	Saturn LS	1.9	2000	51,000	LEV
58	PC	GM	SC1	1.9	1998	105,000	TLEV
59	LDT	GM	Sierra SLE	5.7	1998	188,000	TIER1
60	LDT	GM	Silverado	4.3	1992	224,000	TIER0
61	LDT	GM	Silverado	5.7	1989	390,000	TIER0
62	PC	GM	SL1	1.9	1995	148,000	LEV
63	PC	GM	SL2	1.9	2002	30,000	LEV
64	PC	GM	SL2	1.9	1999	123,000	LEV
65	PC	GM	SL2	1.9	1991	193,000	TIER0
66	LDT	GM	Sonoma SLS	2.2	1996	200,000	TIER1
67	LDT	GM	Tahoe LT	5.3	2001	89,000	LEV
68	LDT	GM	Transport	3.1	1991	200,000	TIER0
69	LDT	GM	Xtreme	4.3	2000	88,000	LEV
70	PC	Honda	Accord SE	2.2	1991	334,000	TIER0
71	PC	Honda	Accord SEI	2.0	1989	302,000	TIER0
72	PC	Honda	Civic CRX	1.5	1991	334,000	TIER0
73	PC	Honda	Civic CX	1.6	2000	68,000	LEV
74	PC	Honda	Civic CX	1.6	1997	126,000	LEV
75	PC	Honda	Civic DX	1.6	1998	128,000	LEV
76	PC	Honda	Civic DX	1.6	1997	139,000	LEV
77	PC	Honda	Civic DX	1.6	1998	145,000	LEV
78	PC	Honda	Integra	1.8	1999	65,000	TIER1
79	PC	Honda	Integra	1.8	1993	270,000	TLEV
80	PC	Honda	Integra LS	1.8	1993	131,000	TLEV
81	PC	Hyundai	Elantra GLS	2.0	2001	54,000	ULEV
82	LDT	Hyundai	Santafe	2.4	2001	36,000	LEV
83	PC	Isuzu	Storm	1.6	1990	201,000	LEV
84	PC	Kia	Sephia	1.8	2001	46,000	LEV
85	PC	Mazda	626 LX	2.0	1996	167,000	TLEV
86	PC	Mazda	Miata	1.8	1997	105,000	TIER1
87	PC	Mercedes Benz	E 320	3.2	2001	49,000	ULEV
88	PC	Mercedes Benz	Slk 320 sport	3.2	2001	36,000	LEV
89	PC	Mitsubishi	Diamante ES	3.5	1998	94,000	TIER1
90	PC	Mitsubishi	Galant ES	2.4	1999	57,000	LEV
91	PC	Mitsubishi	Mirage ES	1.8	2001	80,000	LEV
92	PC	Nissan	280Z	2.4	1983	188,000	TIER0

Table 3.2 (con't)

Number	Vehicle Code	Manufac.	Model	Engine's displacement (l)	Model year	Odometer (km)	Emissions Standard
93	PC	Nissan	Altima XE	2.4	1993	265,000	TIER0
94	LDT	Nissan	Pathfinder SE	3.5	2002	72,000	ULEV
95	LDT	Nissan	Pathfinder XE	3.0	1990	246,000	TIER0
96	LDT	Nissan	Quest gxe	3.0	1996	204,000	LEV
97	PC	Nissan	Sentra XE	1.6	1993	125,000	TIER1
98	PC	Nummi	Geo Prism LSI	1.6	1995	189,000	TLEV
99	PC	Saab	900	2.0	1986	246,000	TIER0
100	PC	Suzuki	Geo Metro LSI	1.0	1989	262,000	TIER0
101	LDT	Toyota	4 Runner	2.7	2000	63,000	LEV
102	LDT	Toyota	4 Runner	2.7	2000	89,000	LEV
103	LDT	Toyota	4 Runner	3.4	1997	131,000	TLEV
104	LDT	Toyota	4 Runner SR5	3.4	2000	28,000	LEV
105	PC	Toyota	Avalon XLS	3.0	2002	56,000	LEV
106	PC	Toyota	Camry LE	2.2	1999	40,000	LEV
107	PC	Toyota	Camry LE	2.2	1996	80,000	TLEV
108	PC	Toyota	Camry LE	2.2	1995	126,000	TLEV
109	PC	Toyota	Camry LE	2.2	1993	143,000	TIER0
110	PC	Toyota	Camry LE	2.2	1998	164,000	LEV
111	PC	Toyota	Camry LE	2.2	1996	190,000	TLEV
112	PC	Toyota	Camry LE	2.0	1986	522,000	TIER0
113	PC	Toyota	Camry XLE	3.0	1994	176,000	TIER1
114	PC	Toyota	Celica ST	2.4	1982	256,000	TIER0
115	PC	Toyota	Corolla	1.6	1996	65,000	TIER1
116	PC	Toyota	Corolla	1.6	1991	155,000	TIER0
117	PC	Toyota	Corolla	1.6	1996	204,000	TIER1
118	PC	Toyota	Corolla	1.6	1993	260,000	TIER0
119	PC	Toyota	Corolla CE	1.8	2001	43,000	LEV
120	PC	Toyota	Corolla CE	1.8	1999	129,000	LEV
121	PC	Toyota	Corolla LX	1.6	1988	157,000	TIER0
122	PC	Toyota	Corrola LE	1.8	2000	84,000	LEV
123	LDT	Toyota	Pick up	2.4	1995	192,000	TIER1
124	LDT	Toyota	Pick up	2.4	1994	252,000	TIER1
125	LDT	Toyota	Pick up	2.4	1987	379,000	TIER0
126	LDT	Toyota	Sienna LE	3.0	1999	75,000	LEV
127	LDT	Toyota	Sienna XLE	3.0	2000	129,000	LEV
128	LDT	Toyota	Tacoma	2.7	1998	128,000	TIER1
129	PC	Toyota	Tercel	1.5	1989	375,000	TIER0
130	PC	Volkswagen	Fox	1.8	1989	150,000	TIER0
131	PC	Volkswagen	GTI	1.8	2000	51,000	TLEV
132	PC	Volkswagen	Jetta	2.0	2000	100,000	LEV
133	PC	Volvo	DL	2.3	1984	225,000	TIER0
134	PC	Volvo	S70	2.4	1999	92,000	LEV



Figure 3.4. Temperature controlled area (cold soak room).



Figure 3.5. Electric mover to push the test vehicles from the soak room to the dynamometer cells.

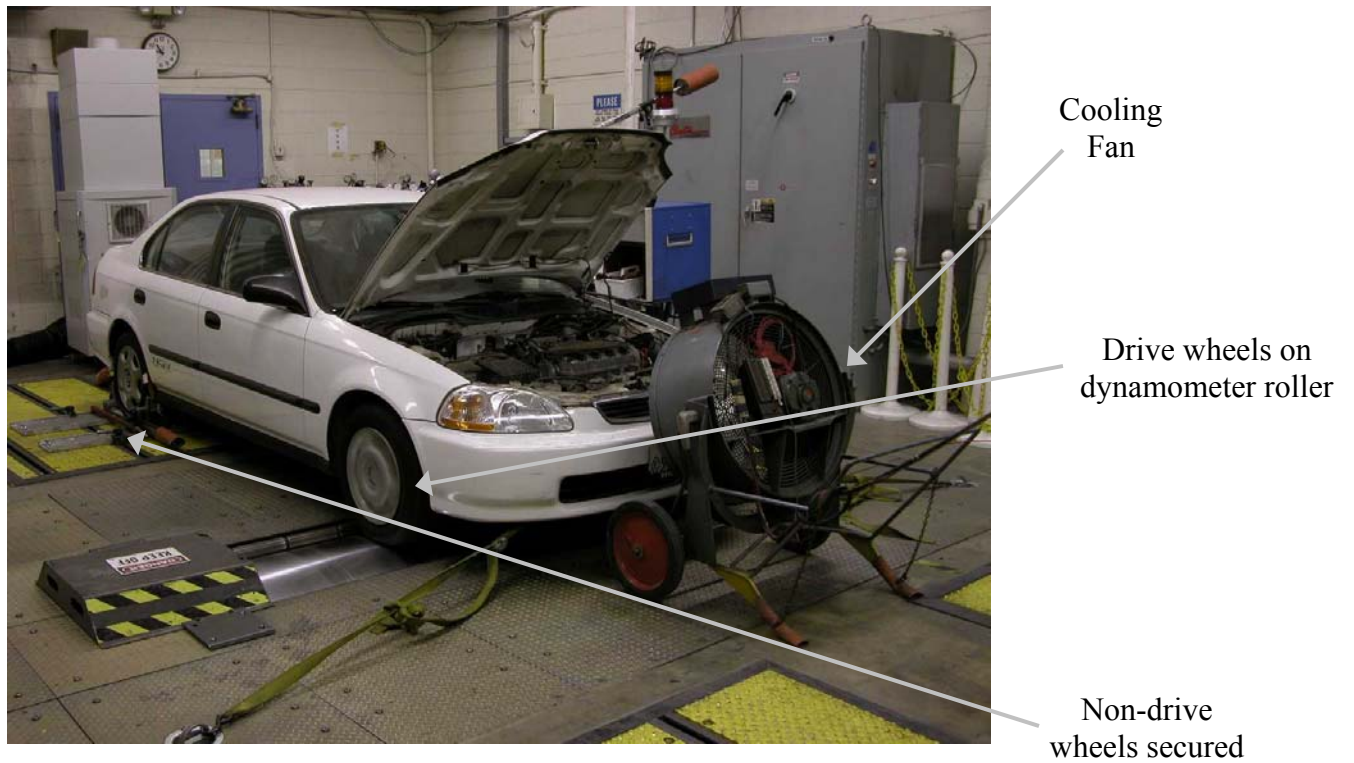


Figure 3.6. Vehicle being tested on a single-roll dynamometer.

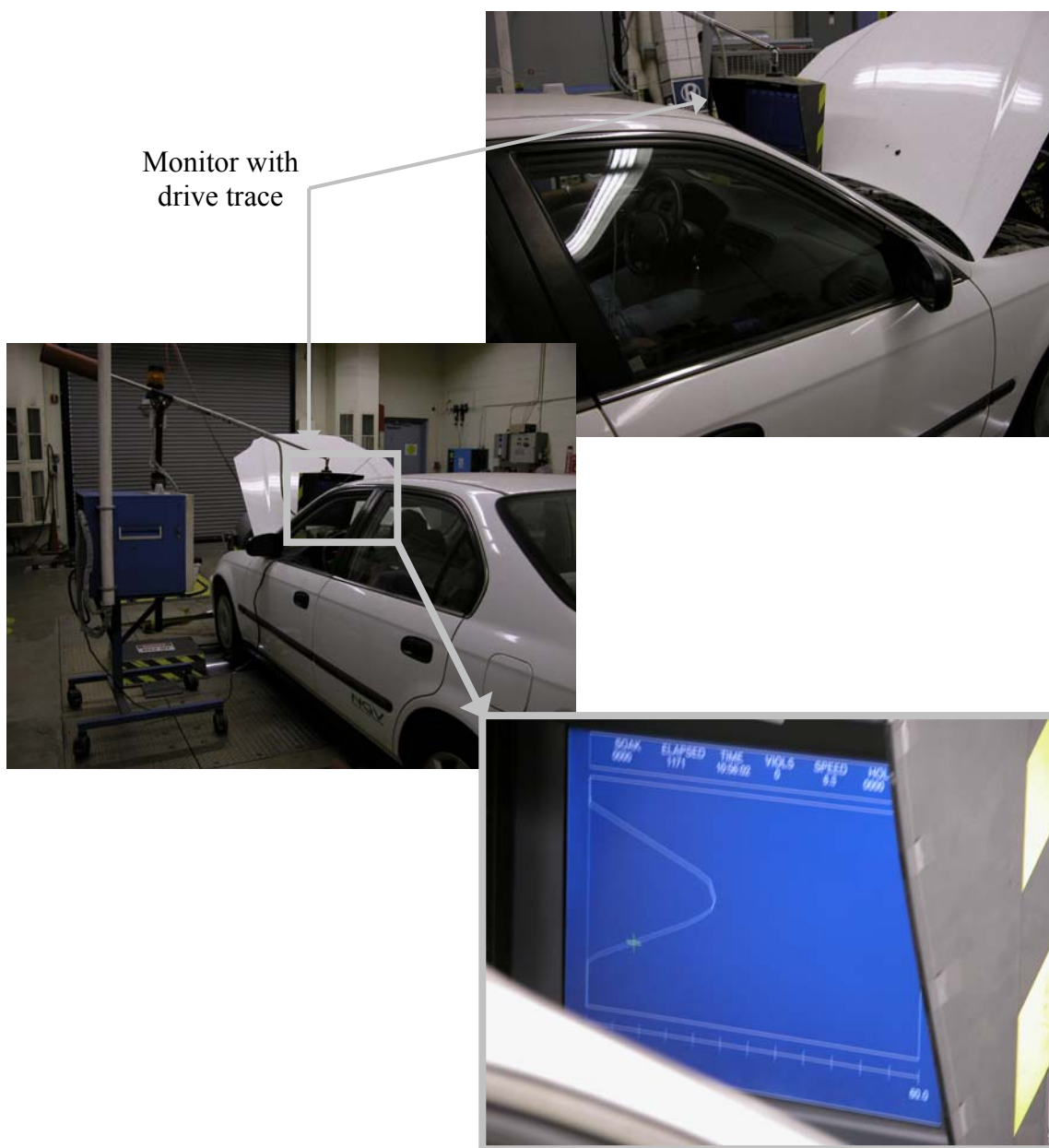


Figure 3.7. Placement of the monitor with drive trace.

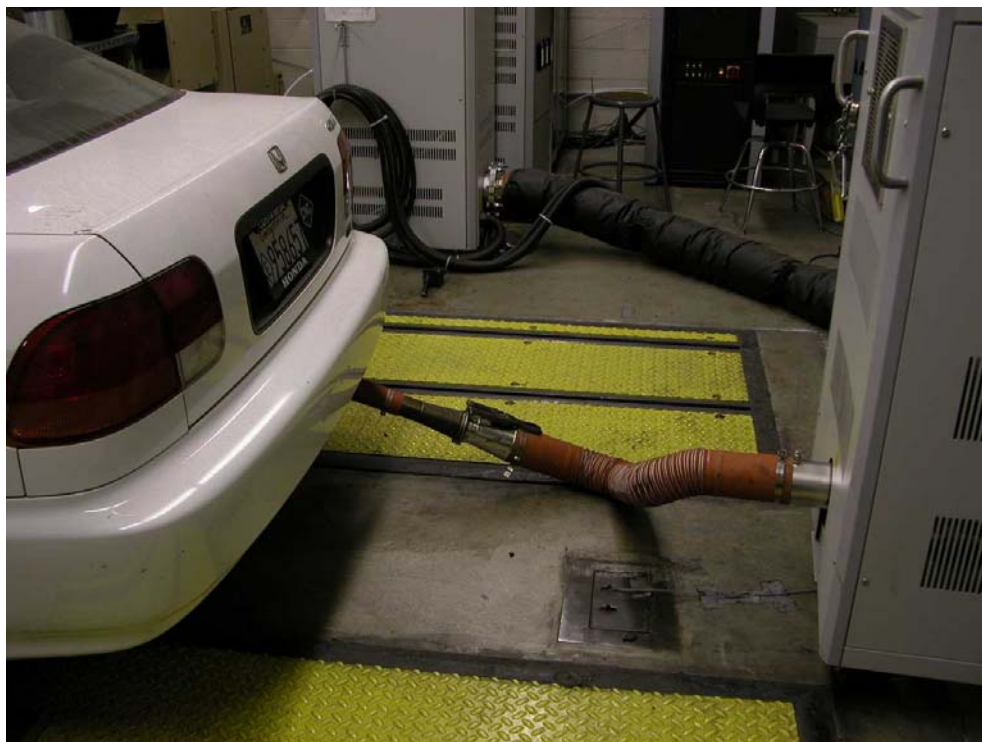


Figure 3.8. Connection between remote mixing tee and vehicle's tailpipe.

3.3.3. *Dynamometer Unit*

Vehicles were tested using a Clayton AC-48 Dynamometer - System IV Controller located in Cell 3 of ARB's HSL. This equipment was equipped with a precision 1.2-meter diameter single-roll dynamometer system that utilized an electric motor to provide desired levels of road load and simulated inertia. These types of dynamometers are known to provide closer agreement with road conditions compared to other commonly used devices. The start up procedure for this dynamometer involved warm-up and coast-down routines at the beginning of each test day. The warm-up procedure consisted of running the dynamometer at 130 km h⁻¹ for 30 minutes. After completion of this routine, a 7-point coast-down (from 105 to 8 km h⁻¹) was performed. These tasks, described in ARB's SOP TP001-C2, were aimed at verifying the road load force (RLF) provided by the dynamometer.

Each test vehicle required a specific RLF, which was determined based on the vehicle's resistance force coefficients and its inertia weight. These values were obtained and input into the dynamometer control software before each test.

3.3.4. *Horiba Constant Volume Sampler Collection System*

Exhaust emissions were collected, diluted, and stored in baked Tedlar sample bags (manufactured from PVF film; for more details see Sun and McMahon, 2001) using a Horiba Model CVS 7200 SLE. The exhaust gases from the test vehicles were routed through the remote mixing tee via an insulated flexible silicon transfer tube attached to the test vehicle's tailpipe (see Figure 3.8). The RMT mixed the raw exhaust emissions from the vehicle with filtered ambient

air from the test cell. Prior to mixing with the exhaust emissions, the ambient air flowed through two filters: a 60% efficiency pre-filter and an activated carbon filter. The amount of dilution air at any given moment of a test was a function of the test vehicle's engine displacement and the speed of the driving cycle (see below).

After dilution, the exhaust sample was transferred from the RMT to the CVS system via a four-inch diameter flexible tube (See Figure 3.9). Critical flow venturis were used to control and keep constant the flow of dilute exhaust into the CVS, driven by a large-capacity blower located on the downstream side of the venturi meter. For most of our testing program we used a CVS flow rate of 29.5 cubic meter per minute (1040 cfm), resulting in average dilution ratios of about 40:1.



Figure 3.9. Connection between CVS unit and remote mixing tee.

Four sample probes on the upstream side of the venturi meter extended into the dilute exhaust emissions stream. Three sample probes collected dilute exhaust emissions to be analyzed by the instrumentation part of the CVS system (for analysis of CO, CO₂, NO_x, CH₄, and total hydrocarbons) and one sample probe diverted a portion of the dilute exhaust emissions to the FTIR instrument (for analysis of N₂O, CO₂, CH₄, CO, and NO_x).

Two of the three sample probes that were part of the CVS system diverted dilute exhaust samples into large (0.28 cubic meter) baked Tedlar sample collection bags for gaseous phase analyses (see Figure 3.10). These bags stored the dilute exhaust samples until they were drawn through the appropriate analyzer at the end of a particular phase of the driving cycle being used. The third of these sample probes diverted the exhaust samples directly into the NO_x analyzer (see below) for continuous real-time analyses.

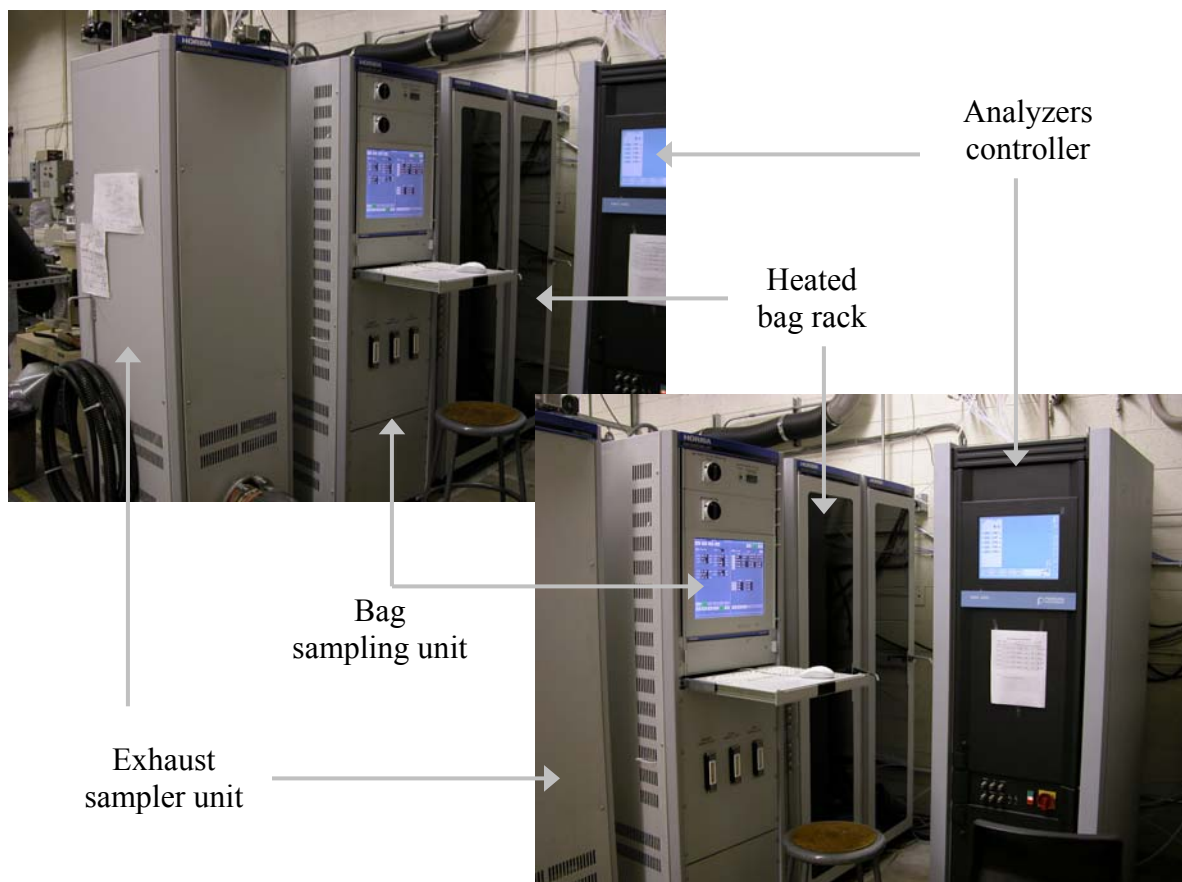


Figure 3.10. Components of the CVS collection system.

3.3.5. *Dynamometer Testing*

Once all the equipment was ready for sample collection, the driver of the vehicle turned on the drive trace and started driving. Driving the vehicle involved following a previously specified drive trace (see below) that was given by the drive trace monitor (see Figure 3.7). This monitor provided a line that moved vertically and horizontally across the screen. The vertical axis represented the test time and the horizontal axis represented the wheels speed. The line in the screen represented the target speed for the vehicle. A cursor in the form of a crosshair was also provided on the screen. The drivers' responsibility was to keep the cursor on the line. The cursor responded to the speed of the vehicle through the dynamometer roller and the driver was able to control such speed through accelerating, decelerating, and braking.

3.3.6. *Driving cycles*

Three driving cycles were used during our testing program: the Enhanced Cold or FTP-UDDS; the UC; and a custom modal cycle (MN₂O), specifically designed during this project to study catalyst formation of nitrous oxide. These test cycles are presented in Figures 3.12 and 3.13.

The FTP is a standardized laboratory experimental method used in Canada and the United States for new and in-use vehicle emissions testing (40 CFR § 86.130-00). The same test parameters and driving cycles are used to ensure that each vehicle is tested under identical conditions, and that the results are consistent and repeatable.

The Unified Cycle, also called LA-92, was created by the California Air Resources Board to supplement the FTP-UDDS and is constructed from segments of driving recorded in the Los Angeles area, including elements of driving that are more aggressive than any found in the FTP-UDDS.

The three types of dynamometer tests used in this study were cold-start cycles and consisted of three phases (or bags) representing different operating modes: the first, cold start emissions; the second, hot running emissions; and the third, hot start emissions.

The UDDS cycle has a total duration of 1879 seconds. Phase one of this cycle is 5.8 km in distance and 505 seconds in duration, with a top speed of 91 km h⁻¹ and an average speed of 42 km h⁻¹. Phase two of this cycle is 6.2 km in distance and 869 seconds in duration with a top speed of 54 km h⁻¹ and an average speed of 26 km h⁻¹. Phase three is identical to phase one. A ten-minute soak period occurs between the end of the second phase and the beginning of the third phase. The engine is turned off during this time.

The Unified Cycle has a total duration of 1735 seconds. Phase one is 1.4 km in distance and 300 seconds in duration with a top speed of 66 km h⁻¹ and an average speed of 22 km h⁻¹. Phase two is 14.2 km in distance and 1135 seconds in duration, with a top speed of 107 km h⁻¹ and an average of 45 km h⁻¹. Phase three is identical to phase one. A ten-minute soak period occurs between the end of the second phase and the beginning of the third phase. The engine is turned off during this time.

The MN₂O cycle has a total duration of 2114 seconds. Phase one is 10.2 km in distance and 770 seconds in duration, with a top speed of 108 km h⁻¹. This phase begins with the engine idling for 180 seconds followed by four accelerations and four steady-state segments. The first two accelerations are fast accelerations (6.5 km h⁻¹ s⁻¹) and the other two accelerations are slow accelerations (1.5 km h⁻¹ s⁻¹). The steady-state portions exhibit a speed of 108 km h⁻¹ for a period of 31 seconds each. Phase two of this cycle, a portion of the second phase of the Unified Cycle, is 6.2 km in distance and 527 seconds in duration. Phase three is identical to phase one. A ten-minute soak period occurs between the end of the second phase and the beginning of the third phase. The engine is turned off during this time.

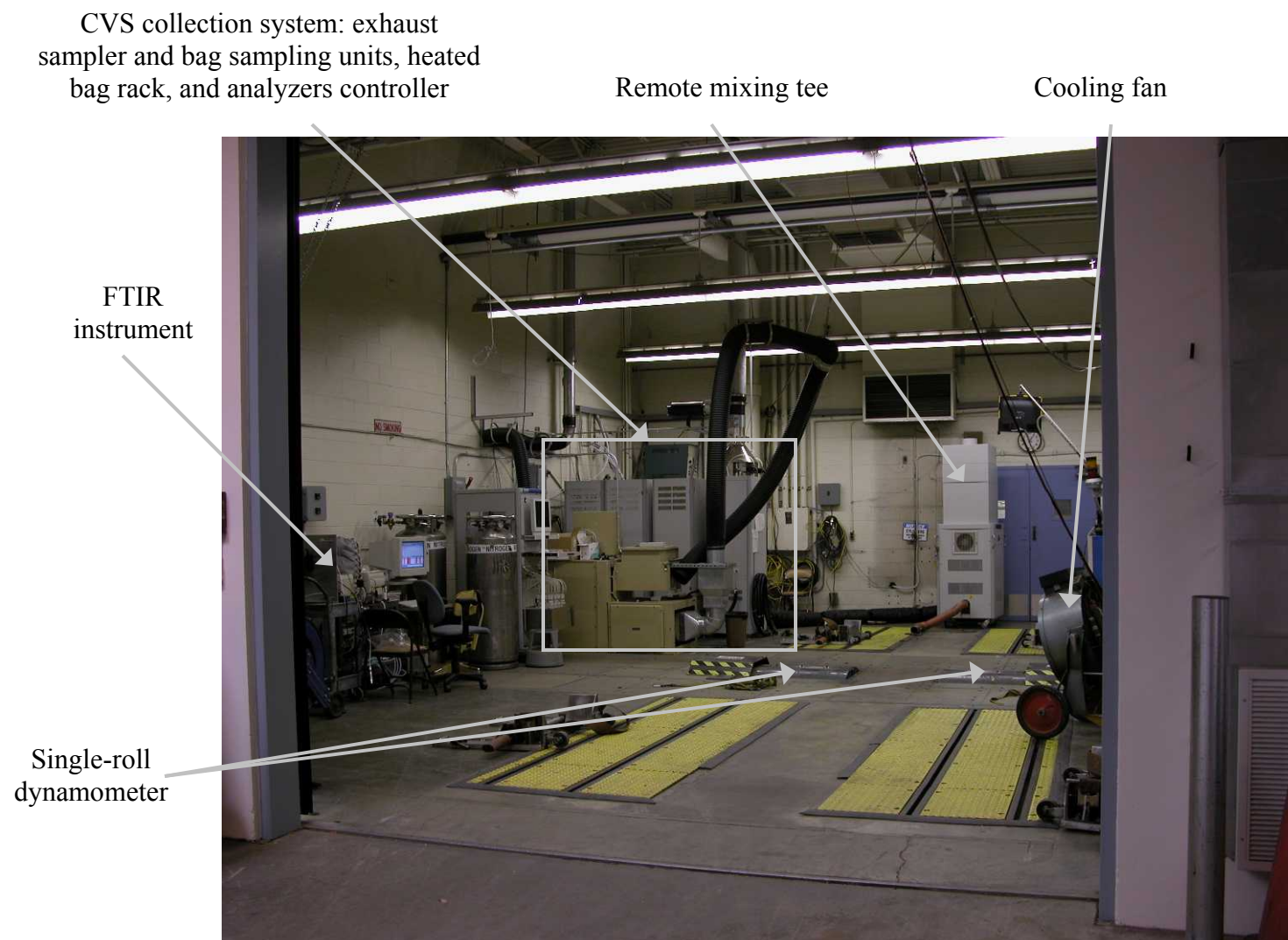


Figure 3.11. Components of the dynamometer testing system used during this study.

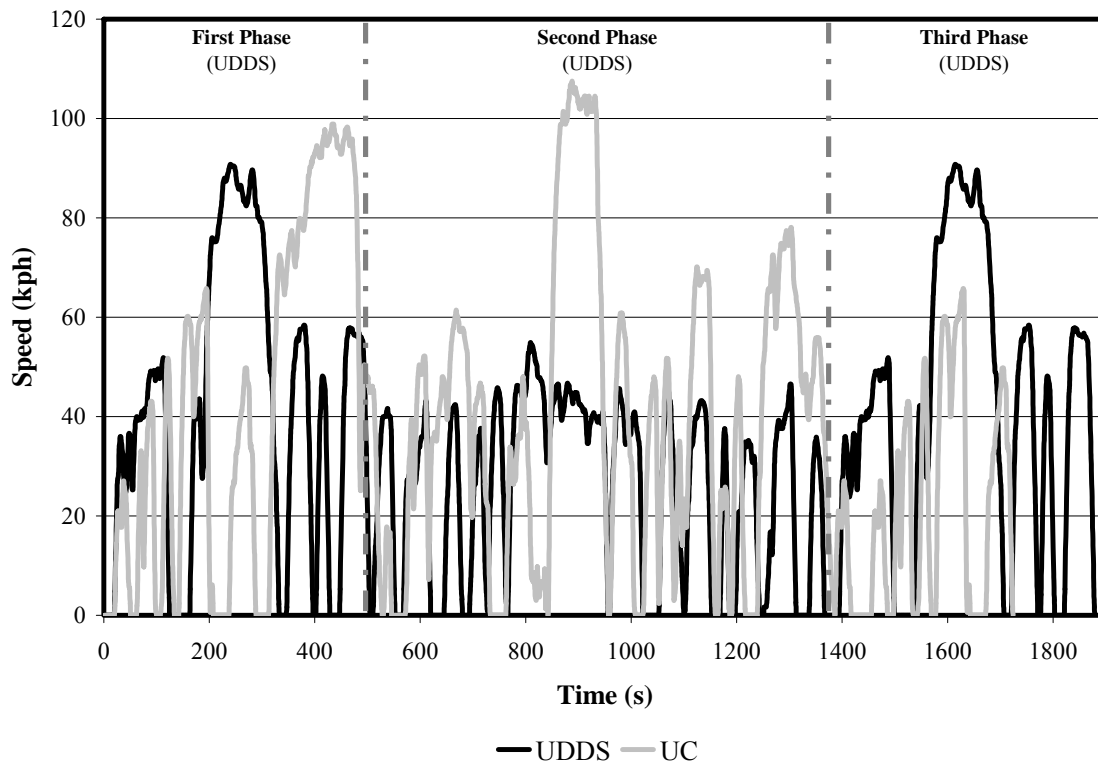


Figure 3.12. Comparison between the UC and the UDDS cycle.

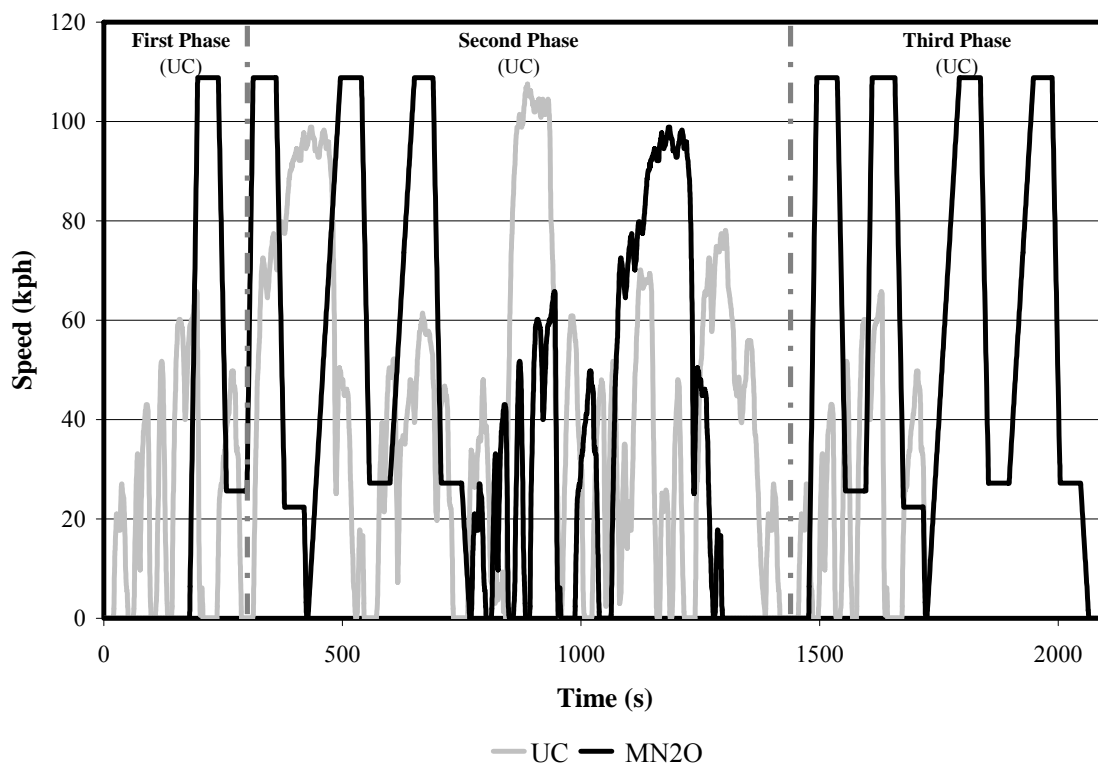


Figure 3.13. Comparison between the MN₂O cycle and the Unified Cycle.

3.4. Catalyst Study Measurements

As mentioned in the summary of approach (Section 3.1), we conducted a series of core catalyst and exhaust stream temperature measurements in parallel to real-time dilute exhaust N₂O and NO_x measurements in a small sample of vehicles for which different catalyst configurations were used. This part of the project involved testing these vehicles with the catalytic converter present on the vehicles when brought into the program (in-use catalyst), testing the vehicles again after removing the substrate of the catalytic converter (empty catalyst), and testing the vehicles once more after installing a new original equipment manufacturer (OEM) catalyst.

To conduct the core catalyst temperature measurements a 1/8-inch hole was drilled through the outer casing of the catalyst into the substrate. The hole was drilled approximately five centimeters into the substrate in the front portion (closer to the engine) of the catalytic converter (see figures 3.14 and 3.15). A thermocouple was inserted into the hole with the tip of the thermocouple embedded five centimeters into the substrate. Friction between the thermocouple and the outer casing/substrate held the thermocouple in place.

Temperature measurements were also obtained from the exhaust stream at the tailpipe using the thermocouple supplied with the CVS collection system. This thermocouple recorded temperatures from the exhaust stream immediately before mixing with ambient (dilution) air.



Figure 3.14. Preparing a vehicle before installing a thermocouple.

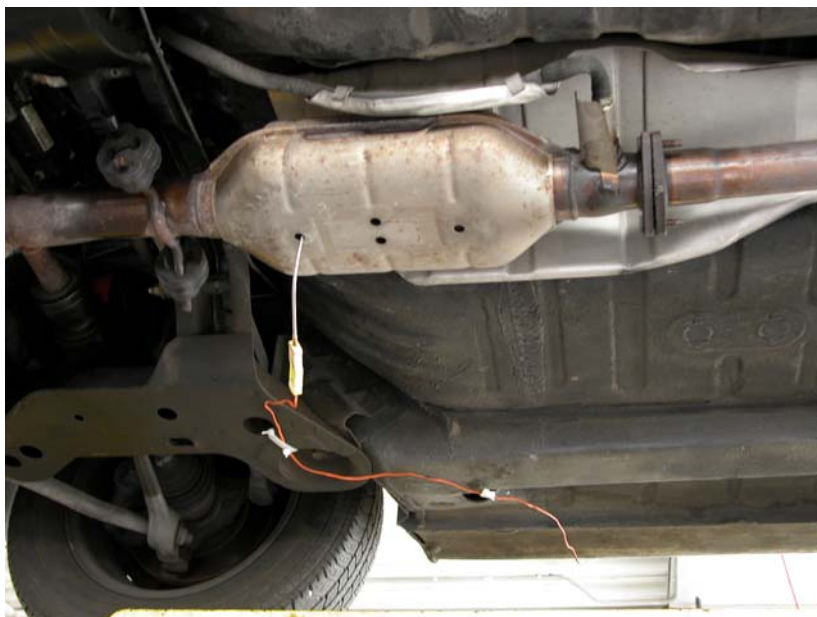


Figure 3.15. Thermocouple inserted in an in-use catalyst.

After testing the vehicles equipped with in-use catalysts, in order to remove and collect their substrate, these devices were detached from the test vehicles, in some cases unbolting flange connectors and in others cutting the exhaust lines with a welding torch (see Figure 3.16). The catalysts were then placed in a vice and a steel bar was inserted into one end of the catalytic converter through the exhaust pipe opening until contact was established with the surface of the substrate. A hammer was used to pound the bar and loosen the substrate (see Figure 3.17). The substrate was broken into small pieces and placed into a container for storage (see Figure 3.18). For a couple of the OEM catalysts, a concrete coring drill was used to loosen the substrate. The process of hammering and drilling (where needed) was repeated until the substrate was completely removed, stored, and labeled for future analyses. Finally, compressed air was used to clean the inside of the catalytic converter removing any remaining dust (see Figure 2.19) and the empty catalytic converter was reinstalled in the vehicle for further testing.

After testing using the empty catalyst configuration, new OEM catalytic converters were installed in the vehicles. These devices were preconditioned before further testing in the dynamometer by driving the vehicles 80 km on a combination of highway (steady state) and surface streets (transient) cycles. Since core catalyst temperature measurements required drilling a hole in the catalysts shell, only exhaust stream temperatures at the tailpipe were measured during new catalyst testing.

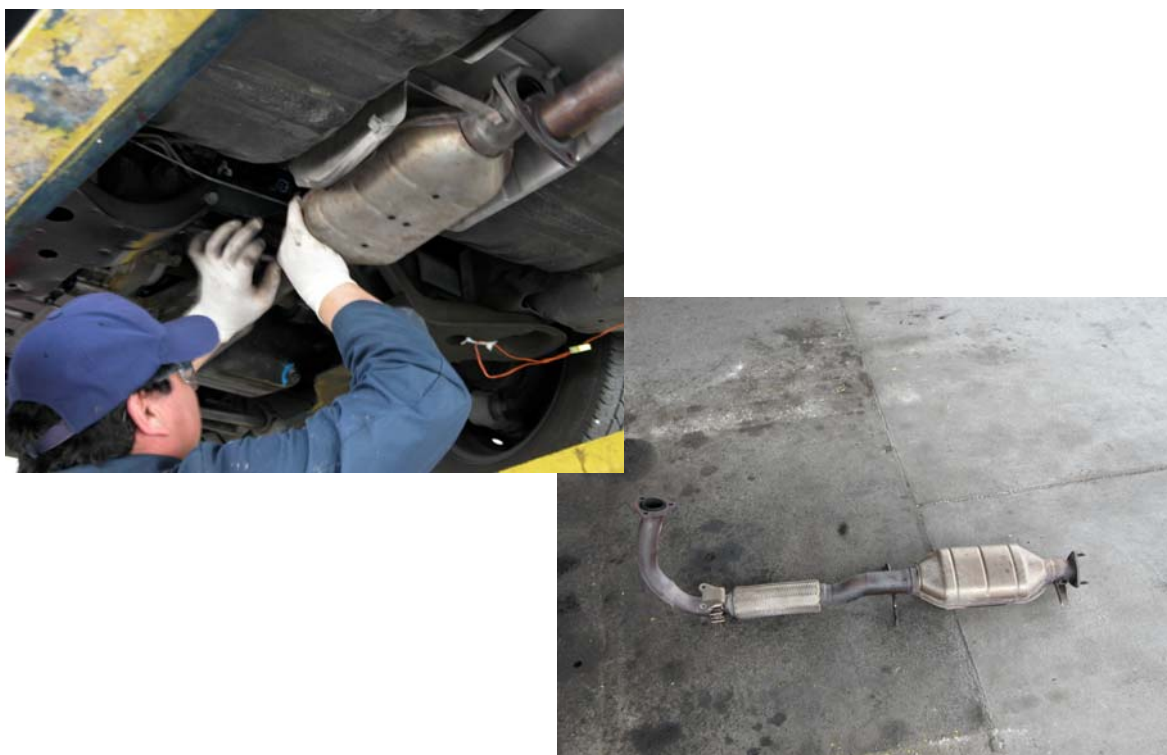


Figure 3.16. Detaching an in-use catalyst.



Figure 3.17. Breaking and removing the substrate of an in-use catalyst.

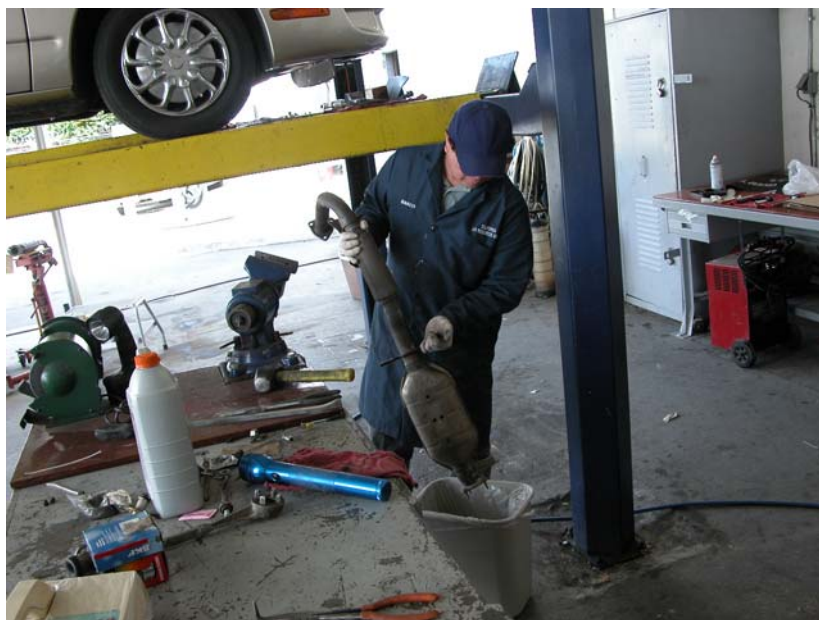


Figure 3.18. Collecting the broken pieces of an in-use catalysts' substrate.



Figure 3.19. Cleaning an empty catalyst.

3.5. Instrumentation

3.5.1. FTIR Spectrometer

During this study, a Nicolet Magna IR-560 optical bench equipped with a Michelson interferometer, a potassium bromide (KBr) beam-splitter, and a mercury cadmium telluride (MCT) detector was used for analyses of vehicle exhaust. The main purpose of this instrument was to determine the concentration of nitrous oxide in dilute exhaust samples. However, the FTIR was also used to quantify other exhaust species including CO₂ (as part of our quality control routines – see Section 3.8), CH₄, CO, and NO_x. A Nicolet 10-meter (2-liters) multi-pass gas cell, equipped with a nickel-coated aluminum body, gold-coated mirrors, and KBr windows was used as the sample chamber. Measurements were made at 0.5 cm⁻¹ resolution, with the gas cell at 100°C and 650 torr. Our method had a limit of detection (LOD) of 0.03 ppm for N₂O and a time resolution (in the real-time data collection mode) of about four seconds.

The Magna IR-560 (see Figure 3.20) is a research-grade, fully upgradeable FTIR spectrometer for experiments in step scan, linear scan, time resolved and rapid scan spectroscopy. This instrument is based upon advanced high-speed digital signal processor technology.

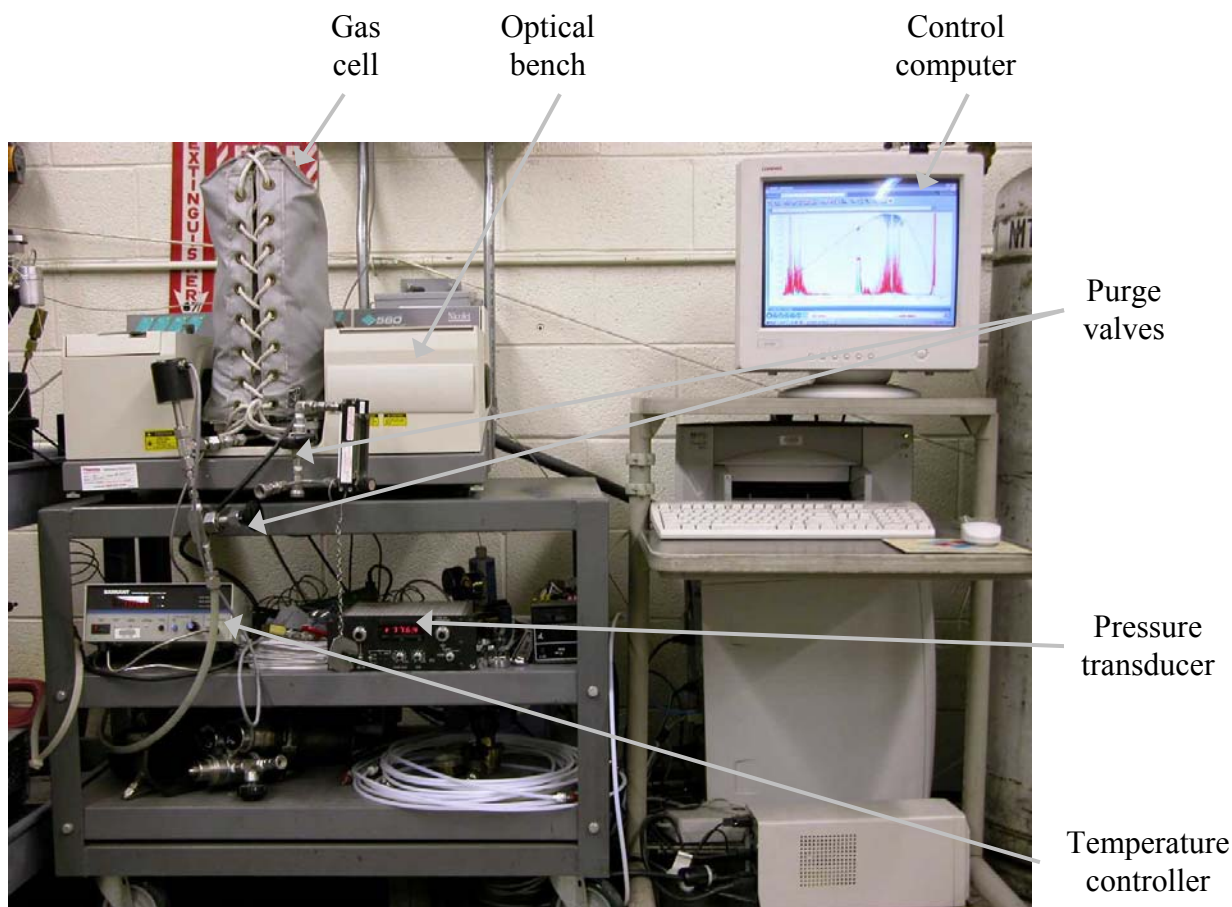


Figure 3.20. FTIR instrument and accessories.

3.5.2. *Chemiluminescence Analyzer*

A HORIBA model CLA-220 Chemiluminescent Detector (CLD) was used to determine NO_x concentrations in dilute exhaust samples. This real-time instrument had a limit of detection of less than 100 ppb and a response time of close to one second.

3.5.3. *Flame Ionization Analyzer*

A Pierburg flame ionization detector (FID) - 4000 LC analyzer was used to determine total hydrocarbons and methane concentrations in dilute exhaust samples with time resolutions of 1.2 and 5 seconds, respectively. This instrument was calibrated for concentration ranges between 0 and 1,000 ppm for total hydrocarbons, and between 0 and 3,000 ppm for methane.

3.5.4. *Infrared Analyzer*

A Pierburg non-dispersive infrared detector (IRD) 4000 was used to determine dilute exhaust concentration of carbon monoxide and carbon dioxide with time resolutions of 2.5 and 1.8 seconds, respectively. The operational range for these instrument was between 0 and 5,000 ppm for CO (limit of detection of less than 1 ppm), and between 0 and 6% for CO₂.

3.5.5. *Air-to-Fuel Ratio Analyzer*

The air-to-fuel (A/F) ratio was determined using a Horiba AFR analyzer model MEXA – 110 lambda. This instrument was equipped with a heated oxygen sensor and was installed between the tailpipe and the remote mixing tee during vehicle tests. The oxygen readings from this instrument were used to calculate the A/F ratio.

3.5.6. *Temperature Measurements*

Exhaust and catalyst temperatures were measured using Omega 'k-type' nickel-chromium (Chromel)/nickel-aluminum (Alumel) thermocouples rated to 800 °C. These readings were recorded directly into the data acquisition system part of the CVS unit.

3.6. Analysis of Dilute Exhaust Samples by FTIR

Exhaust samples collected in Tedlar bags were measured by evacuating the FTIR's gas cell, refilling it with the contents of the bags, measuring the infrared absorbance, and co-adding the results of 64 scans to optimize the signal-to-noise ratio.

To avoid significant interferences from CO, CO₂, and water absorption bands, we used specific windows within the quantitation region (from 2187.6 cm⁻¹ to 2205.2 cm⁻¹) avoiding segments where these absorbencies are strongest. In addition, these species were marked as interfering components in the classical least squares (CLS) algorithm (part of the Nicolet instrument's software) used in conjunction with Beer's law to calculate the concentration of the analyte.

Real-time dilute exhaust samples were measured by flowing them through the FTIR's gas cell at a flow rate of 5 liters per minute, measuring the infrared absorbance, and co-adding the results of 4 scans. The FTIR instrument was able to perform one complete scan every 1.1 seconds. All other settings and procedures were identical to those used for integrated samples collected in Tedlar bags (see above).

3.7. Fuel Characteristics

For most test vehicles, the experiments were performed with the fuel already present when they were recruited, which was likely to be from a local gas station. For those vehicles brought in with insufficient fuel, the fuel tank was drained and commercial California phase 2 gasoline was added, with the characteristics summarized in Table 3.3.

Table 3.3. Characteristics of commercial phase 2 gasoline used in this study.

Physical properties	Fuel type	
	Winter	Summer
Total sulfur (ppm)	13.3	20
Total aromatic (v%)	23.0	21.8
Benzene (v%)	0.60	0.64
Olefin (v%)	5.1	4.5
MTBE (wt%)	11.4	10.0
Oxygen content (wt%)	2.2	1.9
Specific gravity at 60 F	0.74	0.74
Reid vapor pressure (psi)	10.5	6.8
T10 temperature (F)	121	138
T50 temperature (F)	192	198
T90 temperature (F)	307	307

3.8. Quality Control and Quality Assurance Procedures

The FTIR was delivered from the factory with a set of calibrations for 20 different compounds. Upon delivery, the instrument was recalibrated for nitrous oxide, carbon monoxide, and carbon dioxide using primary gas standards. There was no NIST-traceable nitrous oxide standard gas available at the moment the FTIR instrument was configured by monitoring and laboratory division (MLD) staff at the HSL laboratory, nor during the initial stages of this project. However, we were able to determine the accuracy of the FTIR technique used in this work was appropriate. When quantifying a NIST-traceable nitrous oxide gas certified for $10,080 \pm 190$ ppb we obtained concentrations of $9,580 \pm 206$ ppb.

To verify proper instrument performance, a reference mixture containing 100 ppm methane, 100 ppm nitric oxide, and 100 ppm carbon monoxide was analyzed both, once every three months and every time and optical component of the FTIR unit was replaced or serviced. If at least one of these three concentrations differed from the expected values by greater than 5%, the FTIR was to be recalibrated for all compounds of interest. This was never necessary during our testing program.

3.8.1. *Quality Control*

A blank nitrogen sample was analyzed daily to detect contamination inside the gas cell. If these samples yielded nitrous oxide concentrations above the method's limit of detection (see below) after the cell was flushed repeatedly, the analyses were not continued until the causes for this failure were investigated and resolved.

A nitrous oxide control standard was also analyzed on a daily basis. The measured nitrous oxide concentrations were required to be within 5% of a 20-testing-day running average. Failure to meet this criterion halted any other analyses until the causes were investigated and resolved.

Duplicates were run for all four-bag sets (background plus one bag for each phase of the driving cycles) that were part of our experiments. If the difference between duplicates was greater than 10%, the measurements were deemed invalid and needed to be repeated. If repeated measurements continued to fail this quality control (QC) criterion, sample analyses were stopped until the causes for this failure were investigated and resolved.

To assure proper sample labeling and to crosscheck our measurements, FTIR carbon dioxide concentrations were compared with those measured with the instruments part of the CVS collection system (see Section 3.3.4). FTIR CO₂ concentrations were required to be within $\pm 12.5\%$ of the CO₂ concentrations reported by the CVS's instrument. Finally, for each vehicle test, nitrous oxide results were considered suitable data for recording (i.e. valid data) only if the sample bags were analyzed within 96 hours of sample collection, and all other QC criteria were met.

3.8.2. *Uncertainty in Dilute Exhaust Analyses*

The Nicolet Omnic software, provided with the FTIR instrument, uses a CLS algorithm to approximate the observed infrared spectrum of a gas sample with a matrix of reference spectra of both the sample analyte and the interfering compounds. For each region of interest, this program uses the following equation:

$$\vec{O} = \sum_a C_a \cdot \vec{S}_a + \sum_b C_b \cdot \vec{I}_b + \vec{R} \quad (4)$$

where C_a is the concentration of the sample analyte, C_b is the concentration of the interfering compound, O is the observed spectrum, S is the reference spectrum, I is the reference spectrum for interfering compounds, and R is the residual of the calculation. C_b is derived from quantification of the interfering compound in different regions and the software calculates C_a for the best fit of equation (4).

The objective of the CLS algorithm is to minimize the sum of the squares of the residuals, a value that provides a measure of how well the sample spectrum matches the combination of the standard spectra. Therefore, the residual represents the errors of the method in each frequency of the quantitation region and the root-mean-square (rms) of these errors is reported, together with the estimated concentration of each compound, every time the instrument is used.

If this residual (a measure of the uncertainty of each concentration measurement) was greater than 50%, the results were deemed invalid. If repeated measurements continued to fail

this criterion, sample analyses were to be stopped until causes for this failure were investigated and resolved.

3.8.3. Linearity

The linearity of our measurements was verified once every three months or every time an optical component of the instrument was replaced or served. During the several years in which data were collected for this project, our linearity requirements were always satisfied and adjustments were never necessary. This was due, in part, to the relatively small range of N₂O concentrations that are found in dilute exhaust samples (see Section 5.2.3).

For linearity determinations, five gas samples with known N₂O concentrations were prepared using standard gas cylinders and a gas divider. The averages of two measurements of each sample were plotted against the expected concentrations of the samples. The coefficient of correlation between these two populations was to be no less than 0.995 to satisfy our method's linearity requirement. Figure 3.21 shows an example of a linearity check performed in January 2004. In this case, the coefficient of correlation between the observed and the expected N₂O concentrations was 0.9996.

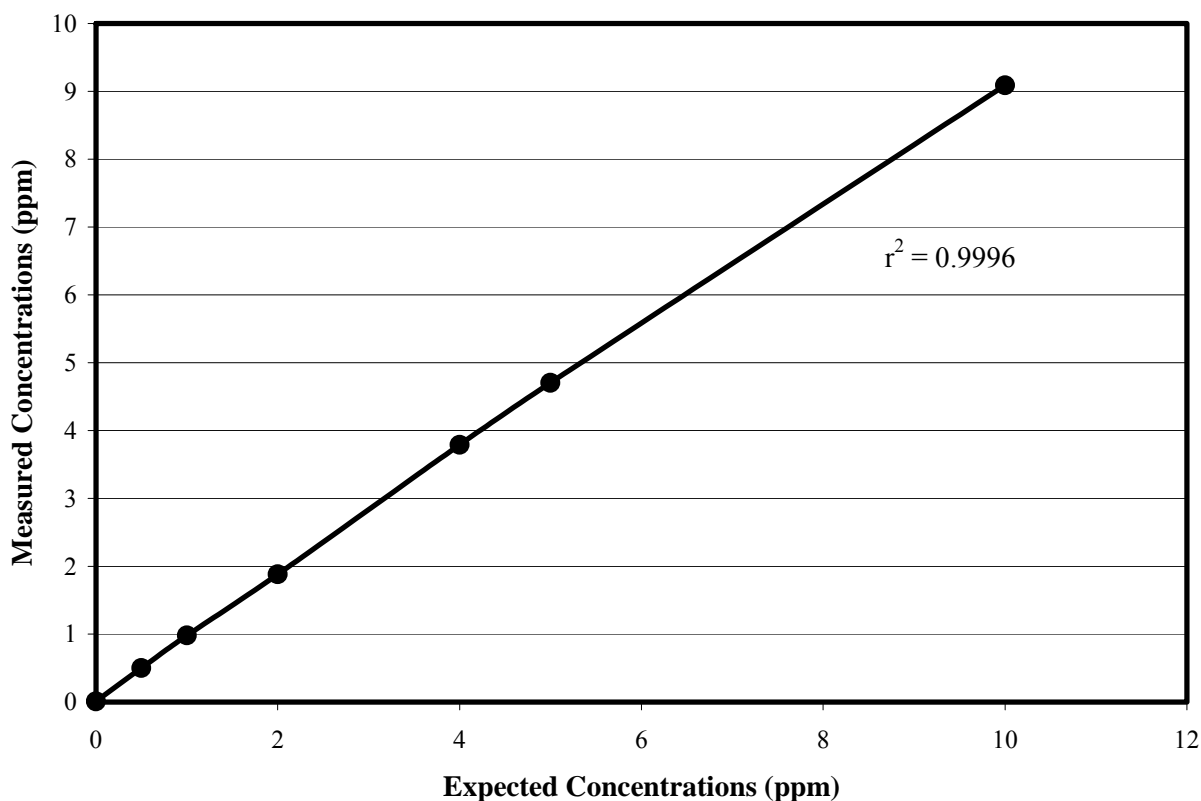


Figure 3.21. Typical results for a nitrous oxide linearity check.

3.8.4. *Limit of Detection*

Limit of detection verifications were conducted once every three months or every time an optical component of the instrument was replaced or served. Similar to the case for linearity, our limit of detection requirements were always satisfied and no adjustments were ever required.

During these verification runs, ambient air was flowed continuously into the gas cell of the FTIR and five consecutive measurements were conducted. The LOD was calculated from the standard deviation of these measurements and the t-student statistic at a 99% confidence level, and compared with our maximum allowed LOD of 0.1. The average LOD of our method was close to 0.03 ppm.

4. PILOT STUDY RESULTS

Table 4.1 summarizes the main characteristics of the 37 vehicles tested during the project's pilot study, which represented a subset of the much larger number of vehicles tested under ARB's 16th vehicle surveillance program. The results and analysis conducted for this part of the study, in which ARB staff collected the emission data, have already been published in the peer-reviewed literature (Behrentz et al., 2004).

According to our literature review, the following factors were deemed to have a significant impact on vehicular N₂O emissions: driving cycle (UDDS, UC), fuel type (sulfur content), catalyst type (oxidizing, TWC, number of beds), presence of pre-catalyst, mileage (odometer readings), and vehicle type (PC, LDT). Therefore, most of the pilot study analyses were focused on these variables.

The interaction between the different variables that affect the formation of nitrous oxide in the catalyst creates a complex set of confounding factors that have to be isolated before performing any type of analysis. Figure 4.1 is a schematic of the data binning process we used in our pilot study to “filter” the database before running the comparative analyses. For example, to evaluate the effect of catalyst type (oxidizing vs. TWC) on N₂O emissions we did not use the entire 37-vehicle database but a subset which included only passenger cars tested under the UDDS using summer fuel. In other words, we established the effect of catalyst type while controlling for type of vehicle, driving cycle, and fuel. The selection tree presented in Figure 4.1 was also designed to optimize the sample size for our comparative analyses.

Although these filters were required to obtain meaningful results, they also compromised the statistical robustness of our results since the sample size for any given analysis was significantly reduced after controlling for the confounding factors. For the example mentioned above we were left with eight vehicles after applying the filters. This issue was addressed and resolved when we performed similar analyses using the entire dataset (from the pilot and main study), as discussed in Chapter 6.

4.1. Regression Analysis

The regression analyses were one exception in which we used the entire 37-vehicle dataset to study the relationships between N₂O and other exhaust species, including THC, CO, CO₂, CH₄, and NO_x. For this type of analysis the confounding-factors issue discussed above does not apply since the species concentrations in the exhaust, instead of being variables, are outcomes of the catalytic processes.

During the pilot study, the highest correlation coefficients (r^2) were found between dilute exhaust concentrations of N₂O and NO_x (0.45), followed by THC and CH₄ (0.15), and finally by CO and CO₂ (< 0.1). These correlations were dependent on the phase of the driving cycles, for example, the correlations between N₂O and NO_x ranged between 0.40 (phase one) to 0.55 (phase two). Figure 4.2 shows scatter plots of dilute exhaust concentrations of both N₂O vs. NO_x and N₂O vs. CO₂, demonstrating the lack of correlation between nitrous oxide and CO₂.

Table 4.1. Characteristics of the vehicles tested during the pilot study.

Number	Catalyst type	Pre-catalyst	Vehicle code	Engine's displacement (l)	Model year	Odometer (km)	Manufacturer	Model
1	TWC, Single bed	NO	PC	2.0	1998	122,000	CHRYSLER	NEON 4 DR
2	TWC, Single bed	NO	PC	4.9	1993	162,000	GENERAL MOTORS	SEDAN DE VILLE 4DR
3	TWC, Single bed	NO	PC	1.8	2000	51,000	VOLKSWAGEN	GTI TURBO
4	TWC, Single bed	NO	LDT	3.0	1993	197,000	FORD	VILLAGER GS
5	TWC, Single bed	NO	LDT	2.8	1985	163,000	GENERAL MOTORS	BLAZER
6	TWC, Single bed	YES	PC	1.6	1995	189,000	NUMMI	GEO PRISM LSI
7	TWC, Single bed	NO	PC	2.3	1984	225,000	VOLVO	DL 4DR
8	TWC, Single bed	NO	LDT	3.1	1991	200,000	GENERAL MOTORS	TRANSPORT
9	TWC, Single bed	NO	LDT	3.0	1990	246,000	NISSAN	PATHFINDER XEV6
10	TWC, Single bed	NO	PC	2.0	1995	102,000	CHRYSLER	NEON 4 DR
11	TWC, Single bed	NO	PC	1.8	1997	105,000	MAZDA MOTOR CORP	MIATA
12	TWC, Single bed	YES	PC	1.6	1993	260,000	NUMMI	COROLLA
13	TWC, Single Bed	YES	PC	2.0	1996	167,000	MAZDA MOTOR CORP	626 LX
14	TWC, Single bed	YES	PC	2.2	1996	80,000	TOYOTA	CAMRY LE
15	TWC, Single bed	NO	PC	1.6	1988	157,000	NUMMI	COROLLA FX
16	TWC, Single bed	NO	PC	1.6	1993	125,000	NISSAN	SENTRA XE
17	TWC, Single bed	NO	PC	3.0	1991	151,000	CHRYSLER	LEBARON LE
18	TWC, Single bed	NO	PC	2.2	1993	143,000	TOYOTA	CAMRY LE 4 DR
19	TWC, Single bed	YES	PC	3.0	2001	3,000	FORD	TAURUS LS
20	TWC, Single bed	YES	PC	2.2	1995	126,000	TOYOTA	CAMRY LE
21	TWC, Double Bed	NO	LDT	3.3	2002	25,000	CHRYSLER	GRAND CARAVAN SPORT
22	TWC, Single bed	NO	PC	3.0	1994	83,000	FORD	TAURUS GL 4 DR
23	TWC, Single bed	NO	PC	3.0	1999	111,000	FORD	TAURUS SE
24	TWC, Single bed	NO	PC	5.0	1983	207,000	GENERAL MOTORS	CAPRICE CLASSIC S/W
25	TWC, Single bed	NO	PC	2.0	1986	246,000	SAAB	900
26	TWC, Single bed	YES	LDT	2.7	2000	63,000	TOYOTA	4 RUNNER 2WD SUV
27	TWC, Single bed	NO	PC	4.9	1991	86,000	GENERAL MOTORS	SEDAN DEVILLE
28	Oxidizing	NO	PC	4.1	1987	276,000	GENERAL MOTORS	EL DORADO 2DR
29	TWC, Single bed	NO	PC	1.0	1989	262,000	SUZUKI	GEO METRO LSi
30	TWC, Single bed	NO	PC	1.5	1989	375,000	TOYOTA	TERCEL HATCH
31	TWC, Single bed	NO	PC	1.8	1993	131,000	HONDA MOTORS	INTEGRA LS 3 DR.
32	Oxidizing	NO	PC	4.1	1986	103,000	GENERAL MOTORS	ELDORADO BIARRITZ
33	TWC, Single bed	YES	PC	1.9	2000	51,000	GENERAL MOTORS	SATURN LS
34	TWC, Single bed	NO	PC	3.3	1992	142,000	GENERAL MOTORS	GRAND AM 4 DOOR
35	TWC, Single bed	NO	PC	2.0	1986	522,000	TOYOTA	CAMRY LE
36	TWC, Single bed	NO	PC	3.8	1986	109,000	FORD	CAPRI GS
37	TWC, Single bed	NO	PC	3.0	1994	176,000	TOYOTA	CAMRY XLE

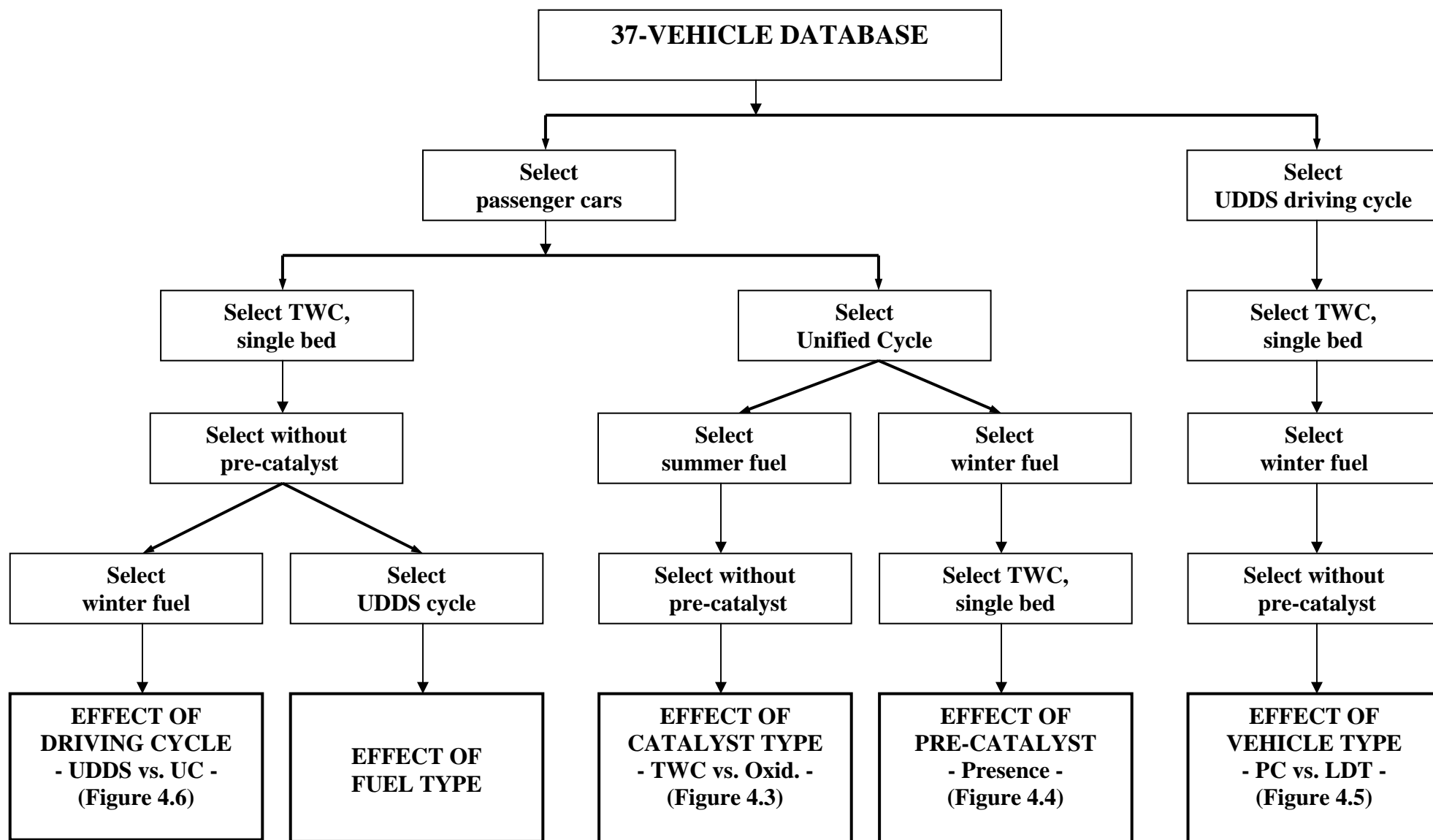


Figure 4.1. Schematic of the data selection and filtering required for comparative analyses (pilot study).

Based on reactions (1) to (3) we expected to find high degrees of correlation between emissions of N₂O and emissions of CO, NO_x, and THC. However, this was not the case for either CO or THC. This is one example in which the sample size used during the pilot study limited our capacity to draw quantitative conclusions. However, it is also possible the apparent lack of consistency between the chemistry of the process and the calculated correlation coefficients resulted because we measured tailpipe emissions (after the catalyst) whereas equations (1) to (3) describe the processes occurring inside the catalyst, and thus engine-out emissions would be required for more accurate calculations. These correlations are further discussed in our analyses of the real-time data (see Section 5.2.3).

4.1.1. Odometer Readings

There is still debate about the degree of correlation between mileage and N₂O emissions. Several studies have reported a significant correlation between these two variables (Pringent and De Soete, 1989; Sasaki and Kameoka, 1992) while others have reached the opposite conclusion (Barton and Simpson, 1994). None of these studies followed a rigorous procedure, such as the one described above, to control for confounding factors, nor did they include a statistically robust samples of vehicles.

We did not find a significant correlation between mileage and N₂O emissions in either our pilot study or our main study. One explanation is that the importance of this variable has been overstated in previous research where the effect of other factors such as catalyst and fuel type were not taken into account. Another possible explanation is related to the inappropriateness of using mileage as a variable in this type of analysis. For example, a vehicle driven for many years could be equipped with a replacement catalyst or could have undergone other modifications in the components of the emissions control system. In this case the relevant variable is the catalyst mileage which would be quite difficult to obtain during in-use vehicle testing programs. This issue is further discussed in Section 5.3.6.

4.2. Effect of Catalyst Type

As depicted in Figure 4.1, to evaluate the effect of catalyst type on N₂O emissions we used the following test vehicle configuration: passenger car/UC/summer fuel/no pre-catalyst. Eight vehicles met this configuration and were used to calculate the average of the emissions during each of the three phases for the different catalyst types. Figure 4.3a summarizes these results.

Consistent with Cho et al. (1989) and Sasaki et al. (1992), during the cold start, vehicles equipped with three-way catalysts produced significantly higher N₂O emissions compared with vehicles equipped with oxidizing catalysts. These results indicate the presence of rhodium in the TWC and its catalytic reduction of nitrogen oxides is an important factor in the production of nitrous oxide. During phase two, however, the average emissions for vehicles equipped with an oxidizing catalyst were slightly higher than for three-way catalyst vehicles (although as seen from Figures 4.3 to 4.6, N₂O emissions were low during phase two). During phase three, the average N₂O emissions were similar for the two different catalyst types.

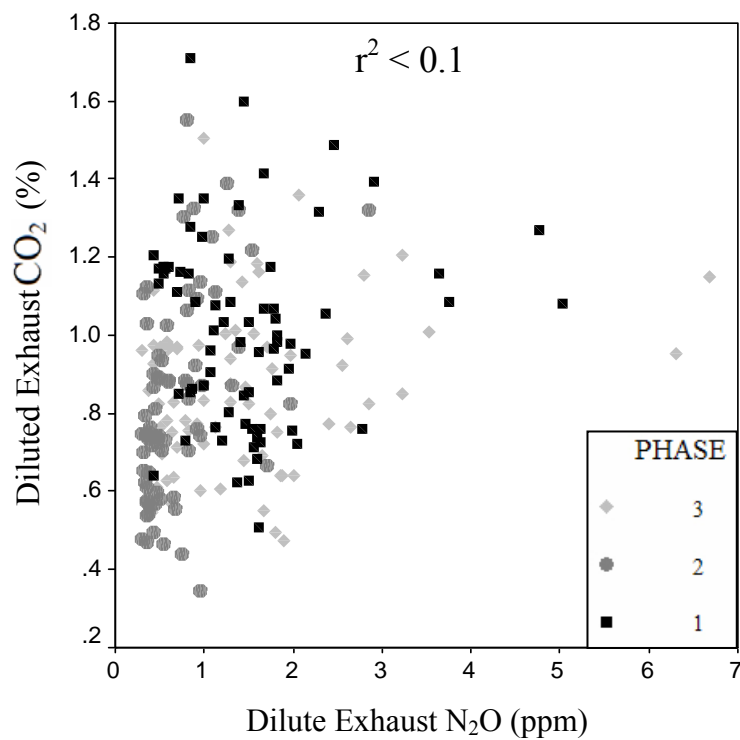


Figure 4.2a. Correlation between dilute exhaust concentrations of N₂O and CO₂.

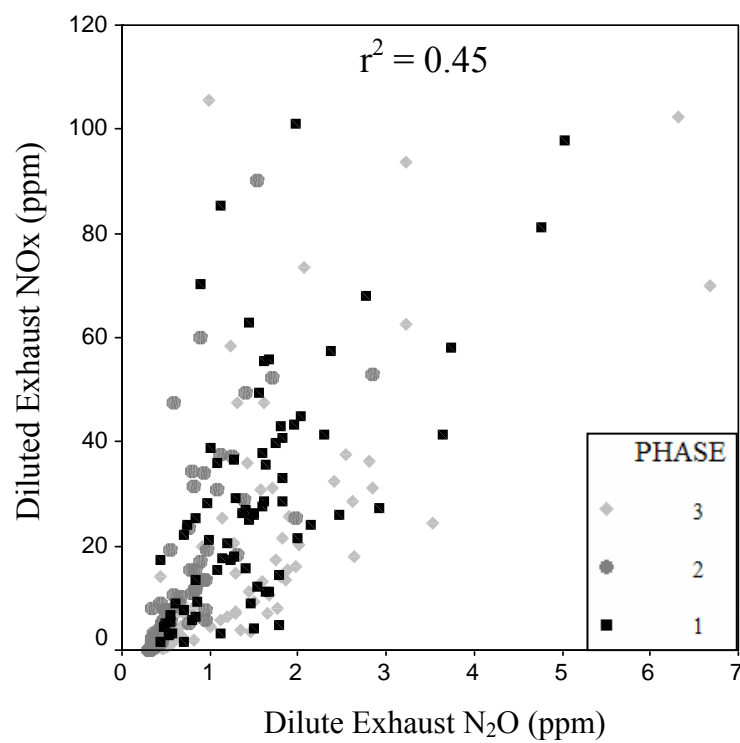


Figure 4.2b. Correlation between dilute exhaust concentrations of N₂O and NO_x.

Although N₂O emissions from oxidizing catalyst vehicles were slightly higher than from TWC vehicles during phase two, the N₂O/NO_x emissions ratio was substantially higher for TWC vehicles for this and the remaining phases of the driving cycle (Figure 4.3b). These results emphasize the importance of the reduction reactions in the catalytic formation of N₂O.

Similar results were obtained when analyzing our entire dataset (pilot and main studies) as discussed in Section 6.3.1.

4.3. Effect of Pre-catalyst

As shown in Figure 4.1, to evaluate the effect of a pre-catalyst device on N₂O emissions, we used the following test vehicle configuration: passenger car/UC/winter fuel/TWC. This data binning process yielded eight vehicles (different from those mentioned above) which could be used to calculate the average of the emissions during each of the three phases for the vehicles with and without a pre-catalyst. Figure 4.4a summarizes these results and shows the presence of a pre-catalyst did not significantly affect N₂O emissions from the tested vehicles. Similarly, as shown in Figure 4.4b, the N₂O/NO_x emissions ratio was comparable between vehicles with and without a pre-catalyst for all phases of the driving cycle.

Based on these results, we did not include this variable (presence of pre-catalyst) during the comprehensive analyses of our integrated samples dataset (see Section 6.3).

4.4. Effect of Vehicle Type

As shown in Figure 4.1, to evaluate the effect of vehicle type on N₂O emissions we used the following test vehicle configuration: UDDS/winter fuel/TWC/no pre-catalyst. Ten vehicles were available, based on these characteristics, to calculate the average emissions during each of the three phases for the different vehicle types. Figure 4.5a summarizes these results and shows vehicle type played a significant role in nitrous oxide emissions.

Specifically, for all three phases, light-duty trucks exhibited significantly higher N₂O emissions compared to passenger vehicles. These results are in agreement with those of Ballantyne et al. (1994), as well as with Barton and Simpson (1994). As shown in Figure 4.5b, light-duty trucks and passenger cars exhibited similar N₂O/NO_x ratios, suggesting that the absolute differences in nitrous oxide emissions (Figure 4.5a) between these two types of vehicles were caused by less stringent NO_x emissions standards for LDT compared to PC.

As discussed in Section 6.3.3, similar results were obtained when analyzing the complete integrated samples dataset.

4.5. Effect of Driving Cycle

As shown in Figure 4.1, to evaluate the effect of driving cycle on N₂O emissions we used the following test vehicle configuration: PC/TWC/winter fuel/no pre-catalyst. Based on these characteristics, twelve vehicles were selected for which we calculated the average emissions during each of the three phases for the different driving cycles. Figure 4.6a summarizes these results and shows a significant difference between N₂O emissions for the two driving cycles. In agreement with Dasch (1992) and Sasaki and Kameoka (1992), the more aggressive cycle (UC)

yielded the highest emissions. As discussed in Section 6.3.2, when considering the entire integrated samples dataset collected during our study, we obtained different results.

The N₂O/NO_x emissions ratios exhibited the same trends as the N₂O emissions during phases 2 and 3 but not during phase 1 (see Figures 4.6a and 4.6b). In particular, N₂O/NO_x emission ratios were higher for the Unified Cycle during phases 2 and 3 and higher for the UDDS cycle during phase 1. These results demonstrate both the complexity of the catalytic reactions that promote N₂O production and the limited scope of the tailpipe N₂O/NO_x emissions ratios (see Section 6.3.5).

4.6. Effect of phase and catalyst temperature

In agreement with Durbin et al. (2001), throughout the majority of our analyses, the most significant differences for N₂O emissions were observed between the different phases within the driving cycles (see Figures 4.3a, 4.4a, 4.5a, and 4.6a). We also found the N₂O/NO_x emission ratios were always higher during phase 3 regardless of the sub-sample of vehicles analyzed (see Figures 4.3b, 4.4b, 4.5b, and 4.6b). These results indicate that, as reported in previous research (Cadde et al., 1997; Odaka et al., 1998; Koike et al., 1999; Riemersma et al., 2003) and consistent with the findings of our main study (see Section 6.3), catalyst temperature plays a major role in the formation of N₂O. This issue will be further discussed in Section 5.3.4, in the context of our real-time results.

4.7. Other Variables

Transmission type (automatic, manual) and engine design (L, V) did not play a significant role in observed N₂O emissions. Results obtained for engine displacement and fuel efficiency were not conclusive and more data are required to draw dependable conclusions. In addition, other variables such as vehicle manufacturer were not used as part of this analysis since they could involve numerous confounding factors that could not be controlled given the limited sample size of our pilot study.

Although they were considered a potentially important variable, applicable emission standards were also not included in our data analysis during the pilot study because adding another level to our data binning process would have limited even more the dependability of our conclusions, due to further reduction in the sample size for the comparative analyses. However, this variable was part of our comprehensive analyses of the complete integrated samples database and proved to be among the most important factors in determining nitrous oxide emissions from light-duty vehicles (see Section 6.3.4).

4.8. N₂O Emissions and N₂O/NO_x Emissions Ratios

During the pilot study we found an overall N₂O/NO_x emissions ratio of 0.095 ± 0.035 , with a range between 0.01 and 0.14. The lowest ratio (0.01) occurred during phase 2 in an oxidizing-catalyst vehicle and the highest (0.14) during phase 3 in a TWC-equipped vehicle. Similarly, a relatively small variability was found for the overall NO_x emission factors ($300 \pm 70 \text{ mg km}^{-1}$). These pilot study findings, in conjunction with the relatively high degree of correlation established between emissions of N₂O and NO_x (see Section 4.1), validate the procedure followed by ARB to estimate overall N₂O emission factors based on NO_x emissions and N₂O/NO_x emissions ratios.

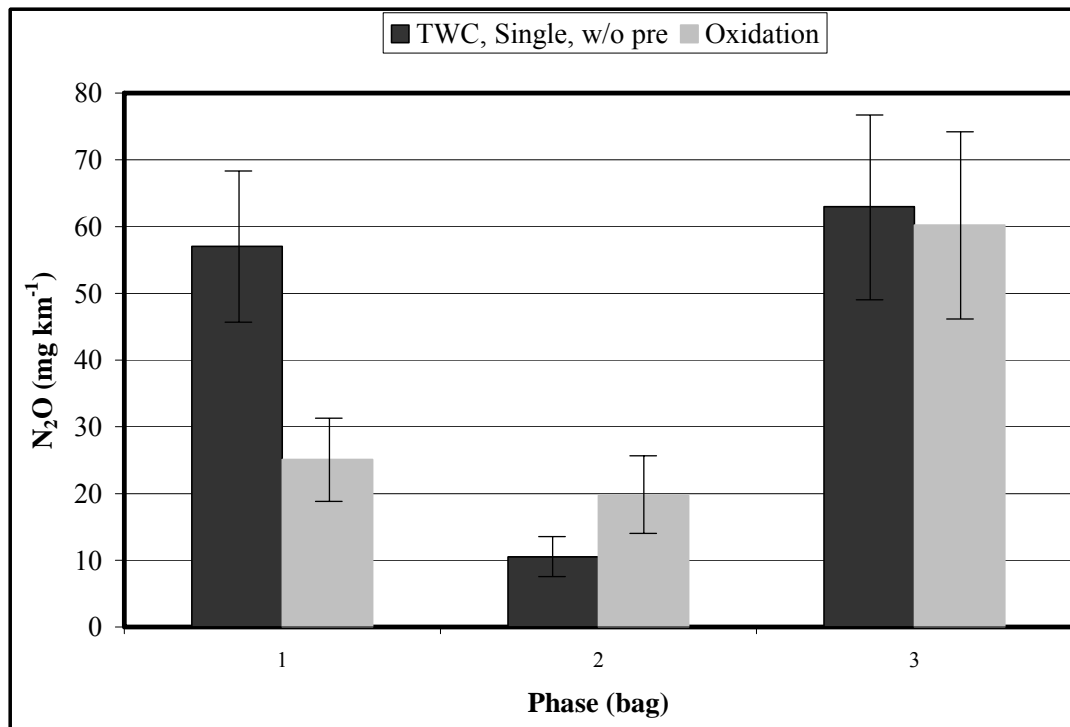


Figure 4.3a. Effect of catalyst type on N₂O emissions (sample of eight vehicles –six TWC, two oxidation catalyst).

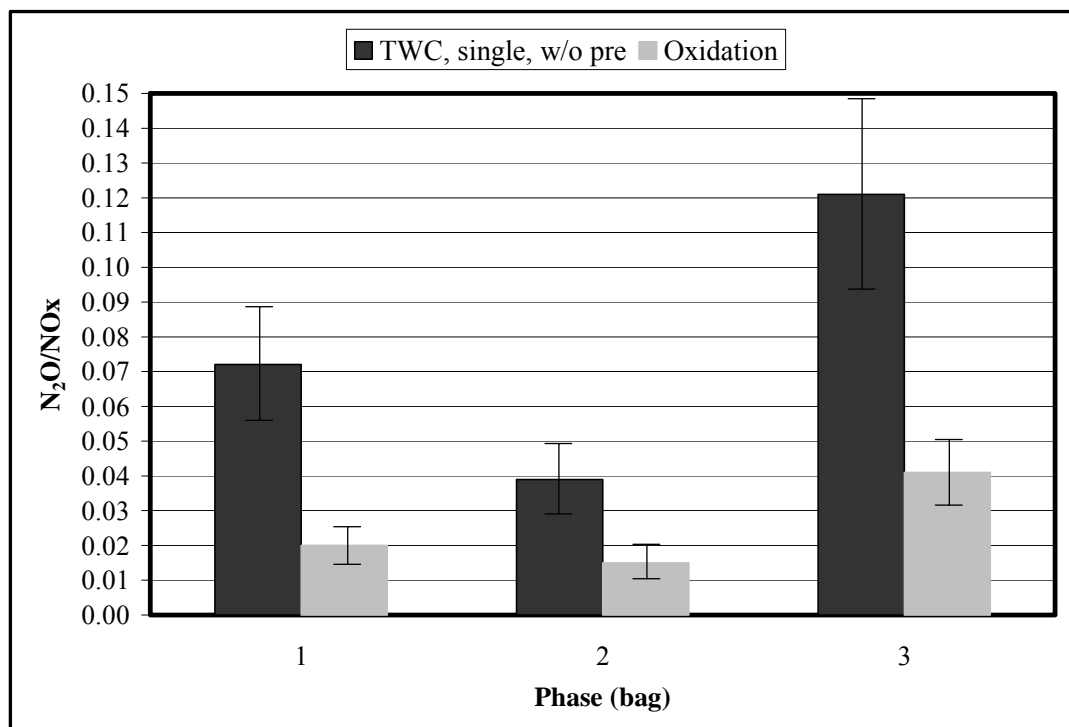


Figure 4.3b. Effect of catalyst type on N₂O/NO_x emissions ratio.

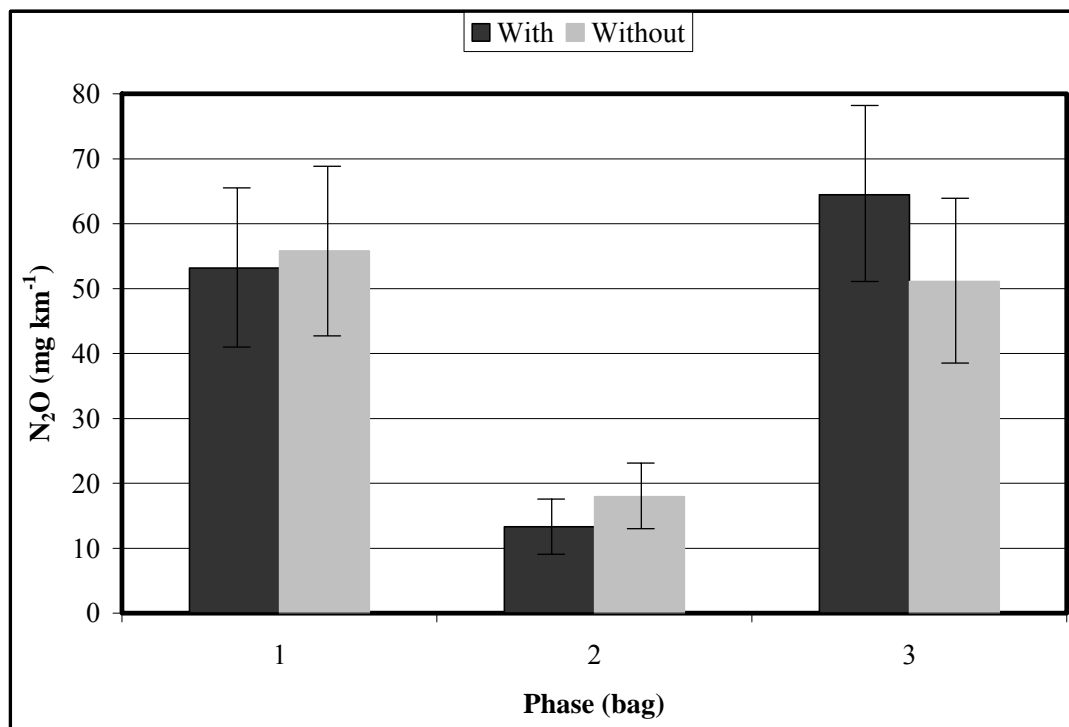


Figure 4.4a. Effect of presence of pre-catalyst on N₂O emissions (sample of eight vehicles –two with pre-catalyst, six without).

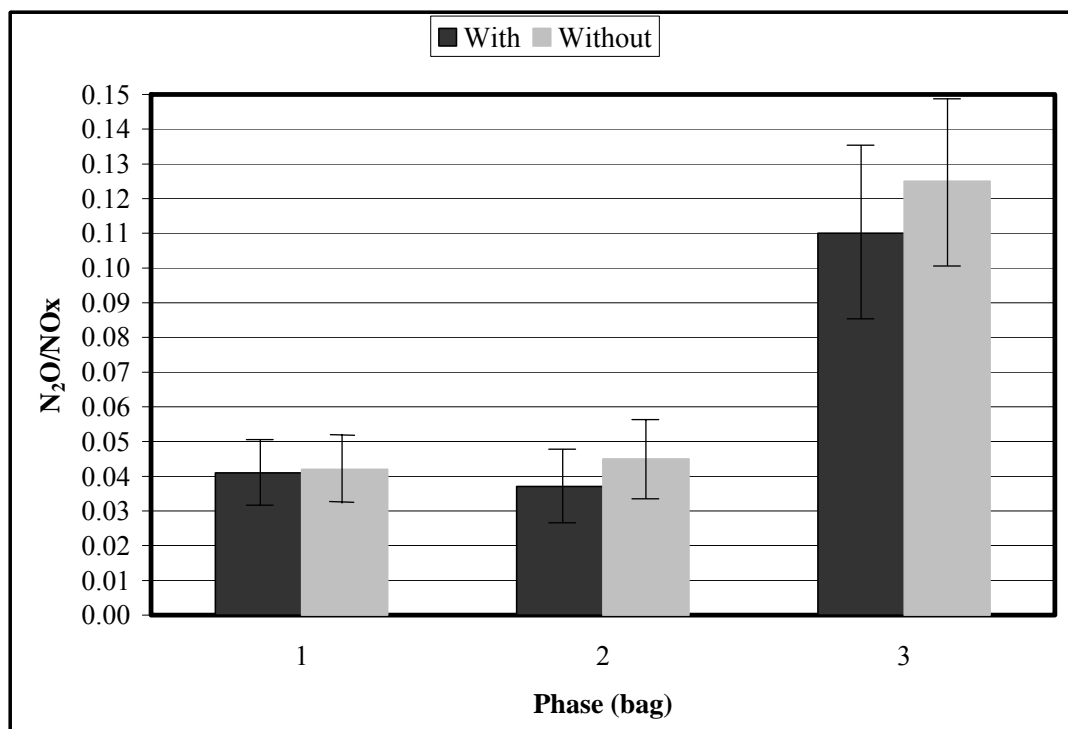


Figure 4.4b. Effect of presence of pre-catalyst on N₂O/NO_x emissions ratio.

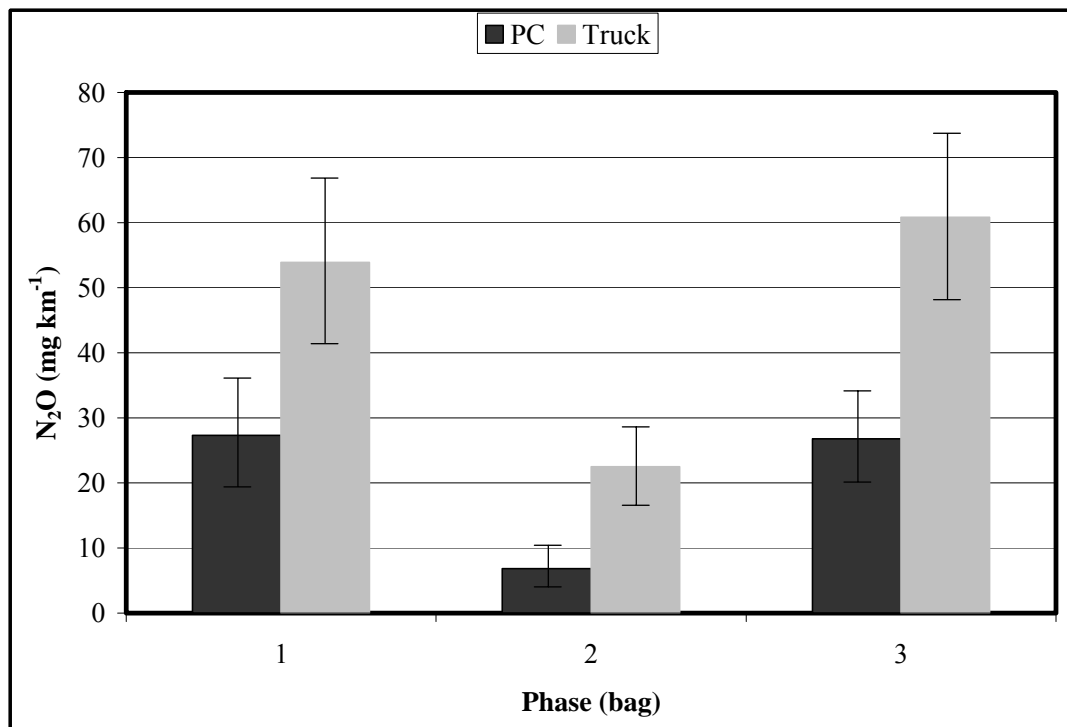


Figure 4.5a. Effect of vehicle type on N₂O emissions (sample of ten vehicles –six PC, four truck)

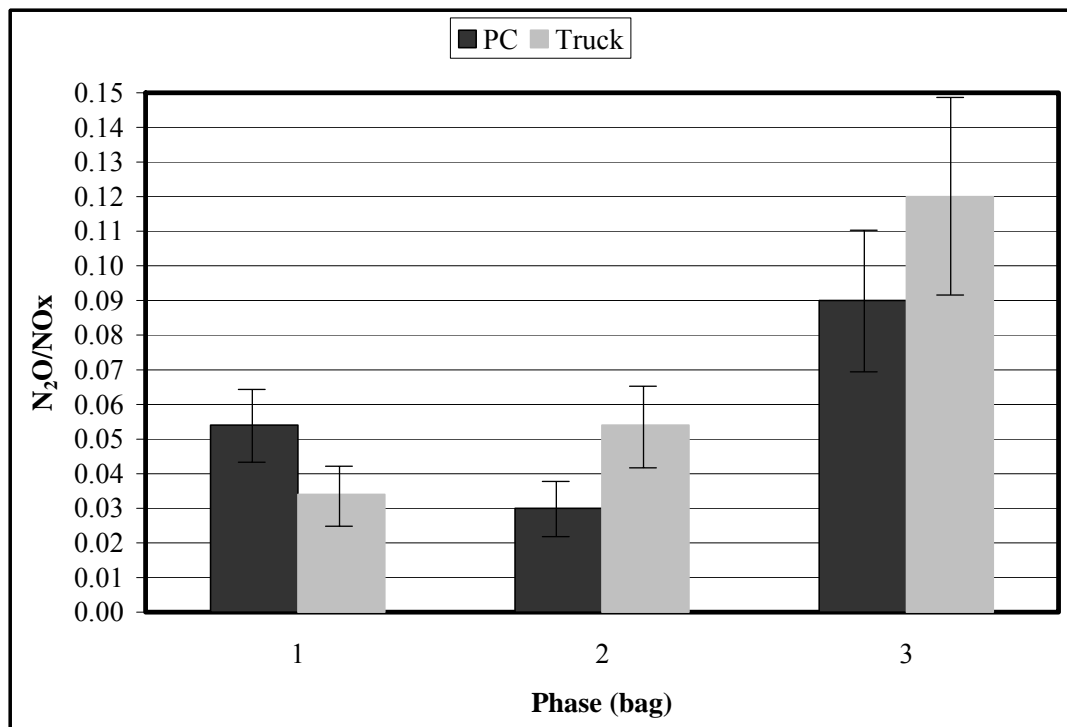


Figure 4.5b. Effect of vehicle type on N₂O/NO_x emissions ratio.

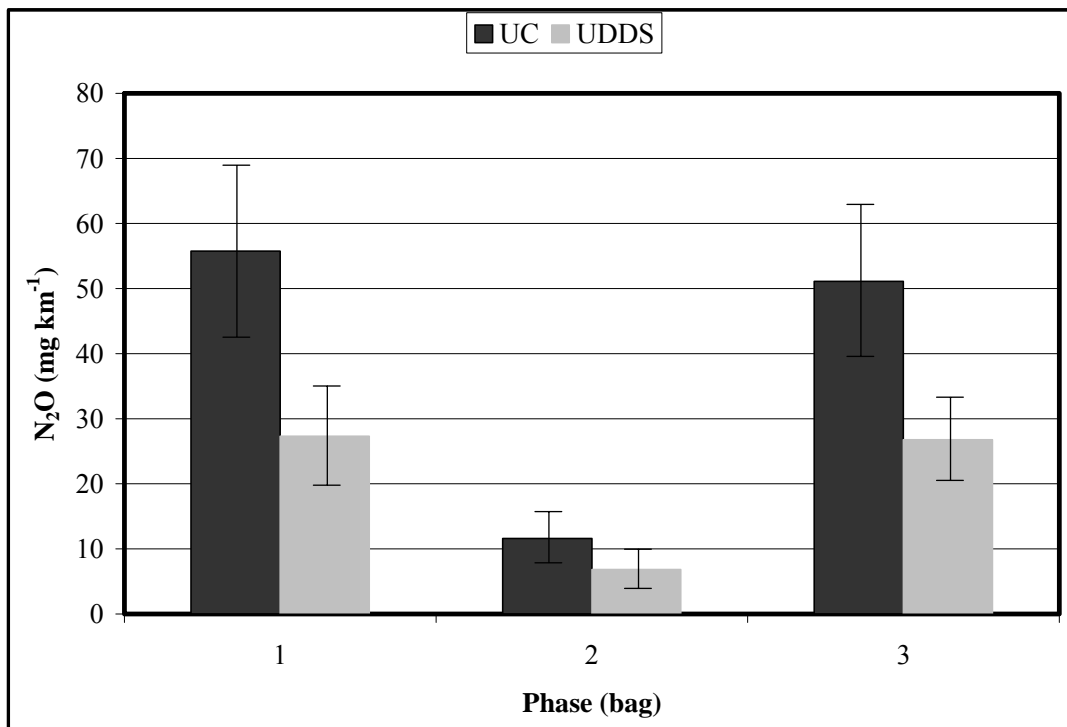


Figure 4.6a. Effect of driving cycle on N₂O emissions (sample of twelve vehicles –six UC, six UDSS).

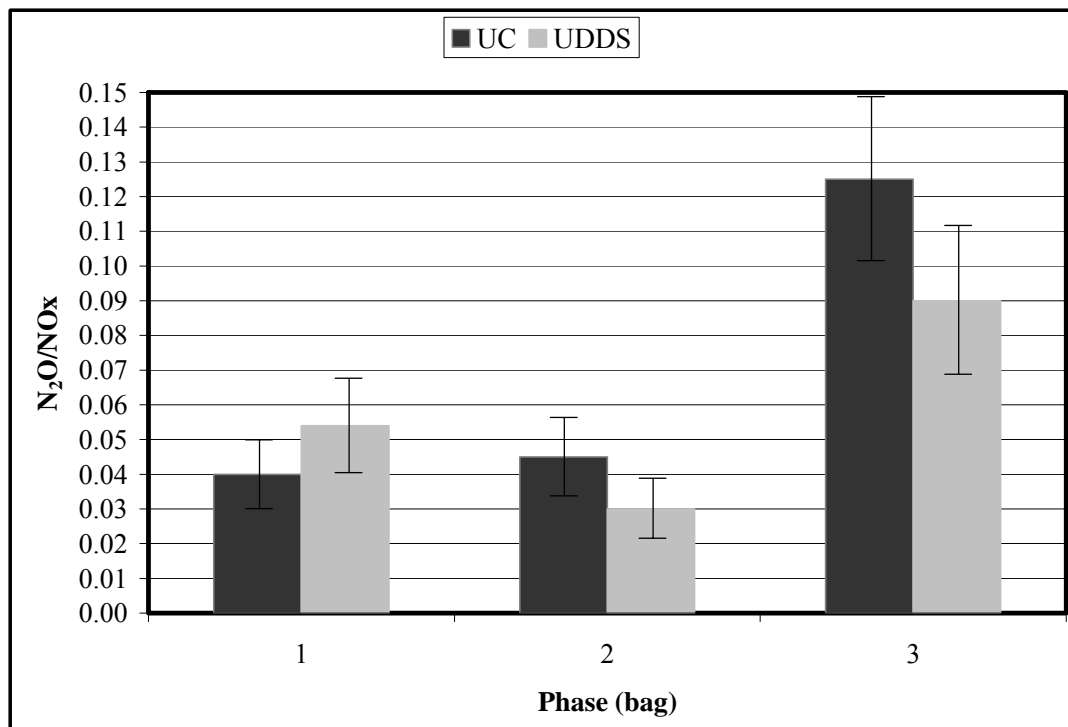


Figure 4.6b. Effect of driving cycle on N₂O/NO_x emissions ratio.

However, as discussed elsewhere, nitrous oxide forms as an intermediate product during the catalytic reduction of NO. Whereas N₂O formation is highly dependent on catalyst temperature, NO production is highly dependent on engine temperature, and these two conditions are not necessarily correlated throughout the entire course of a testing cycle. In addition, as discussed in Section 6.3.5, the application of the tailpipe N₂O/NO_x emissions ratios is limited. These ratios can be extrapolated to other fleets or used for emissions forecasting only if equivalence in terms of the fleets' emissions standards can be established. In summary, to generate accurate N₂O emission inventories, it is necessary to apply more sophisticated analyses, including data binning and data selection procedures, as presented in this document.

4.9. Emission Factors

Table 4.2 presents the average emission factors for nitrous oxide for the different cases considered in our analyses of the pilot study data. The combined effect of the numerous factors addressed in our study yielded a large range of values for N₂O emissions from passenger cars and light-duty trucks.

Among the 37 vehicles tested during the pilot study, the lowest overall N₂O emissions (2 mg km⁻¹) were produced by a 2001-year model passenger car equipped with a three-way double bed catalyst and pre-catalyst, with less than 3,000 kilometers on the odometer, tested under the FTP-UDDS driving cycle. The highest overall emissions (100 mg km⁻¹) were produced by a 1991-year model light-duty truck equipped with a three-way, single bed catalyst without pre-catalyst, with more than 200,000 kilometers on the odometer, tested under the Unified Cycle. Thus, a factor of 50 between the lowest and the highest N₂O emissions was observed for the different vehicles and phases during our pilot study.

The average N₂O emissions factor for the 37 vehicles tested during the pilot study was 20 ± 4 mg km⁻¹, significantly lower than previous reports of average values of ~35 mg km⁻¹ (Urban and Garbe, 1979; Smith and Carey, 1982; Pringent and de Soete, 1989; Dasch, 1992; Ballantyne et al., 1994; Barton and Simpson, 1994; Michaels et al., 1998).

The differences between the emission factors reported by earlier studies and those presented here are likely to be related to the introduction of new technologies, involving more efficient catalytic converters using smaller quantities of precious metals while reaching their operational temperatures after shorter periods of time. This issue is discussed further in Section 5.3.6.

4.10. Conclusions from Pilot Study

The N₂O emission data generated for 37 vehicles allowed a preliminary analysis of the main factors that affect nitrous oxide emissions from passenger cars and light-duty trucks.

During the pilot study, we established that catalyst type, driving cycle, and vehicle type were among the relevant factors determining N₂O emissions from gasoline powered light-duty vehicles and thus these variables were considered during the analyses of the main study datasets (Section 6.3). In addition, throughout the majority of our analyses of the pilot study data, the most significant differences in N₂O emissions were observed between the different phases (bags) within the driving cycles, indicating that operating conditions, including catalyst temperature, play a major role in the catalytic formation of N₂O. Based on these results, we added more than

160 real-time experiments to our experimental design during the main study, in which core catalyst and exhaust temperature measurements were collected in parallel with dilute exhaust N₂O concentration data.

Table 4.2. Average N₂O emission factors.

Selection criteria	Number of vehicles	Average N ₂ O (mg km ⁻¹)			
		Phase 1	Phase 2	Phase 3	Entire cycle
UDDS/Ethanol/LDT/TWC/ Double bed/no pre-catalyst	1	6	4	7	5
UDDS/Summer/PC/TWC/ Single bed/no pre-catalyst	16	32	14	35	23
UDDS/Winter/PC/TWC/ Single bed/no pre-catalyst	6	27	7	27	16
UC/Summer/PC/TWC/ Single bed/no pre-catalyst	6	57	10	63	16
UC/Winter/PC/TWC/ Single bed/no pre-catalyst	6	56	12	51	17
UC/Summer/PC/Oxidizing	2	25	20	60	23
UC/Winter/PC/TWC/ Single bed/pre-catalyst	2	53	13	64	19
UDDS/Winter/LDT/TWC/ Single bed/no pre-catalyst	4	54	22	61	39

¹Weighted average computed according to 40 CFR § 86.144-90.

Our results suggested that although overall N₂O/NO_x emissions ratios and overall NO_x emissions could be used to estimate N₂O emission factors for a particular fleet, more sophisticated analyses should be applied to generate accurate emissions inventories, in particular, controlling for confounding variables. These analyses are also useful to investigate the factors that affect N₂O emissions, an understanding required to design appropriate emissions control strategies as reflected in the results obtained from the analyses of the real-time data and the entire integrated database (see Section 6.3.5).

5. RESULTS OF REAL-TIME MEASUREMENTS

Based on the results of our pilot study and to better understand the process of catalytic formation of nitrous oxide, we determined it was necessary to conduct experiments involving real-time data collection. During this part of the study, we completed 161 experiments on 53 vehicles using three driving cycles (see appendix B).

Real-time testing was conducted in parallel with collection of integrated samples during 82 experiments. In addition, we collected real-time A/F ratio data during 11 experiments, real-time exhaust temperature data during 122 experiments, and real-time NO data during 72 experiments.

As mentioned in Section 3.4, as part of our real-time testing program (see Figure 5.1), we collected core catalyst temperatures for a selected sample of vehicles that were tested under three catalyst configurations (in-use catalyst, empty catalyst, and new catalyst).

5.1. Correlation between Real-Time and Integrated Samples

The FTIR spectroscopic procedure used during this study for determination of nitrous oxide concentrations in bag samples of automotive exhaust is considered the standard method by ARB and a detailed standard operating procedure (SOP # MLD-133) is available at ARB's website (www.arb.ca.gov). However, the method we used to collect *real-time* N₂O concentration data for dilute exhaust samples was developed and refined in the course of this project and is yet to be recognized as a standard analytical method by the ARB. Therefore, to validate our real-time results, we established the correlation between samples that were analyzed in parallel, using the two methods (real-time and bags). The scatter plot presented in Figure 5.2 illustrates the high correlation ($r^2 = 0.95$; $N = 82$) and lack of significant bias (around 5%) between results obtained from the two methods, and demonstrates the validity of our real-time dataset.

5.2. Preliminary Analyses

During the preliminary analyses described below, we studied the results from 126 experiments that included A/F ratio and exhaust temperature data as well as real-time concentrations of N₂O, NO, and other exhaust species.

5.2.1. *Air to Fuel Ratios*

Second-by-second A/F ratio data were collected in 11 experiments. There was almost no difference in the overall behavior of this variable among the experiments (not even when using different driving cycles). Figure 5.3 shows a typical time series for A/F measurements from a passenger car during a UC dynamometer test.

During the first 300 seconds of this cold-start test, the A/F ratio exhibited a slight upward trend that is likely to be related to the time required for the engine and catalyst to reach their optimal operational temperature (see Section 5.3.4). During this period, the test vehicle was operating under an air/fuel mixture with more fuel than required (rich conditions). About 400 seconds after the start of the test, the A/F ratio stabilized close to the stoichiometric value of 14.9 and stayed relatively constant for the remainder of the cycle. Although the signal was slightly noisy, its variations were small (std. dev. = 1.6) and occurred within a well defined interval

(between 15 and 20). Diverging A/F ratios were more common above (lean conditions) than below the stoichiometric value and it was evident from our data that an air/fuel ratio cap of less than 20 was preset for the operation of this and other test vehicles.

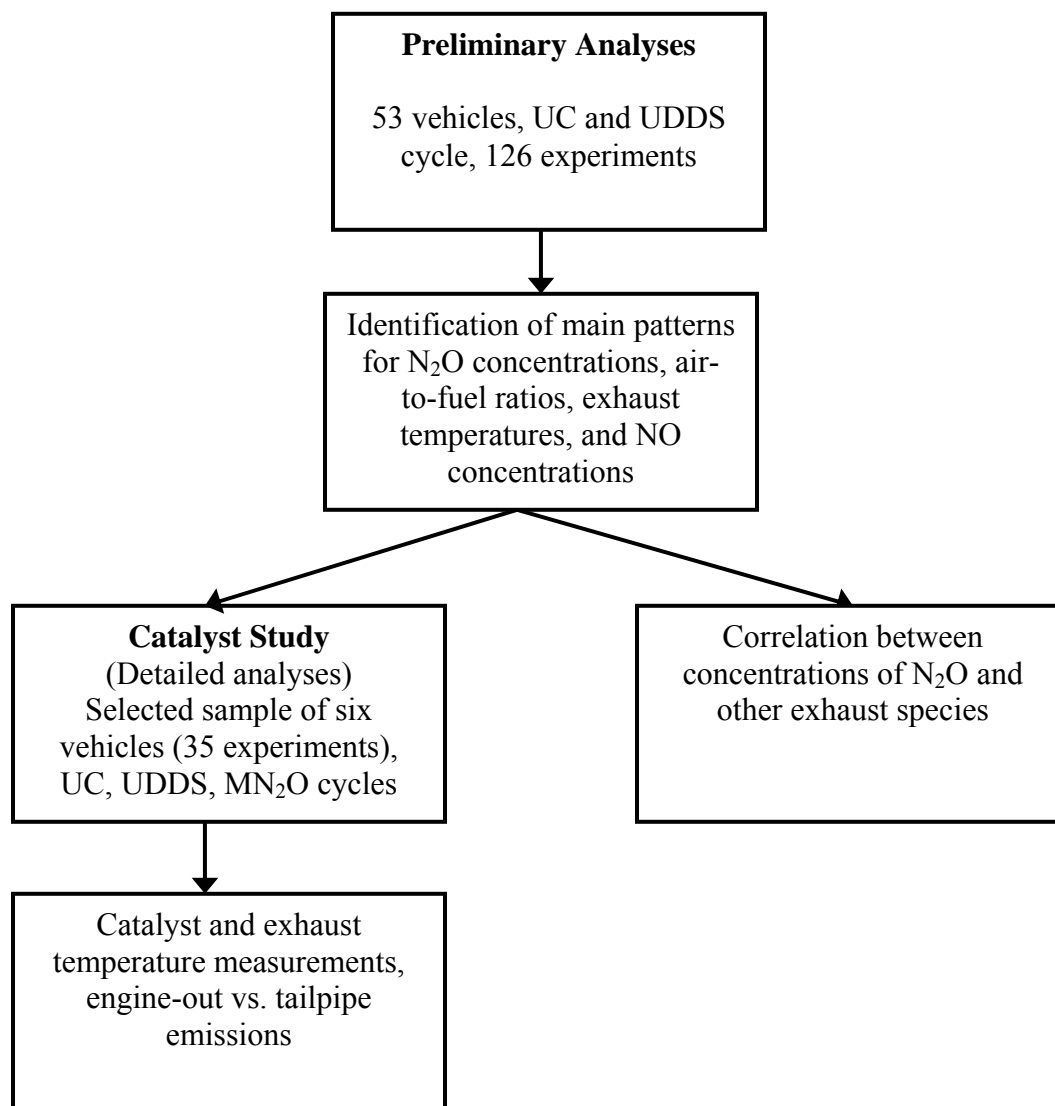


Figure 5.1. Summary of approach for real-time testing program.

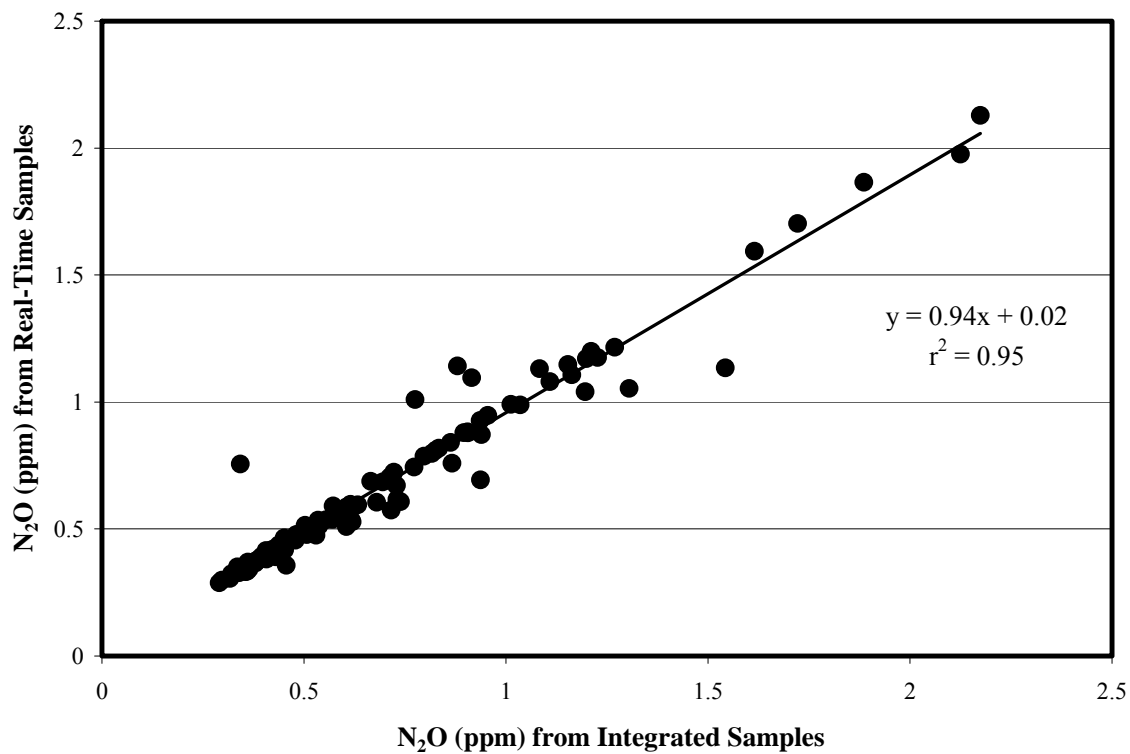


Figure 5.2. Correlation between real-time and integrated analyses of dilute exhaust samples.

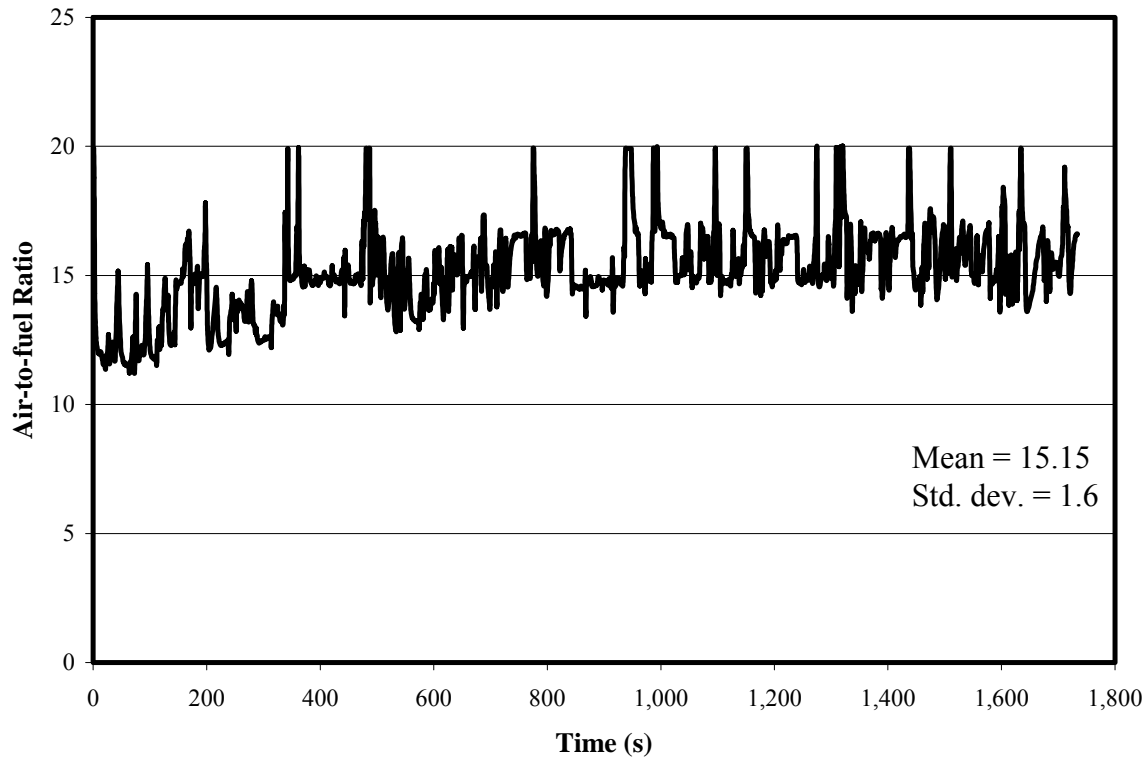


Figure 5.3. Typical A/F ratio measurements from a passenger car during a UC dynamometer test.

Figure 5.4 depicts a cumulative frequency distribution of all A/F ratios collected during our study, providing further evidence that the oxygen sensors of the test vehicles were performing as expected and kept the air/fuel mixture close to specifications and assuring optimal performance of the catalytic converters. This figure shows that close to 70% of all A/F data points were within the 14.9 ± 1 interval.

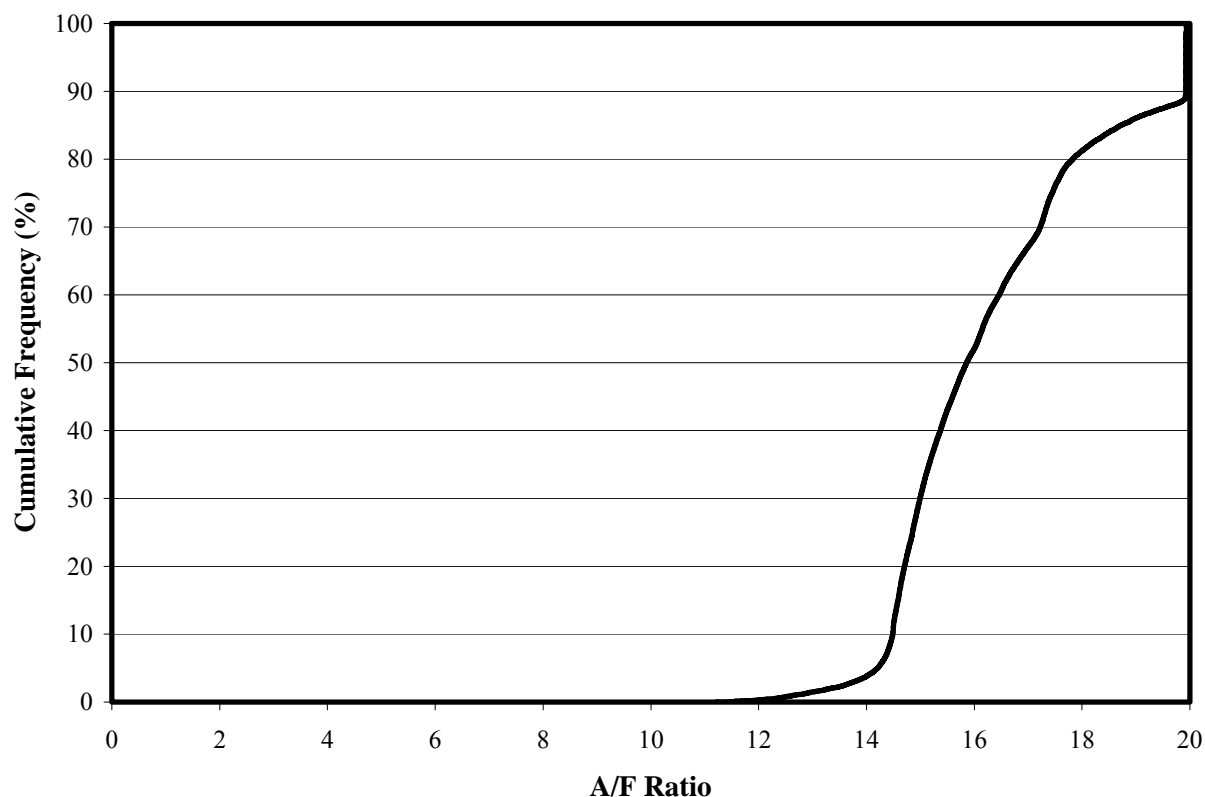


Figure 5.4. Cumulative frequency distribution for A/F ratio data.

5.2.2. Exhaust Temperatures

Exhaust temperatures were collected during 88 experiments, without counting those in which core catalyst temperatures were also collected (see Section 5.3.4.1). These measurements were conducted in the mixing tee before the exhaust was diluted with filtered ambient air during dynamometer tests. Figure 5.5 shows an example of an exhaust temperature time series. These data were obtained from a 2002 passenger car tested under the UDDS cycle. Although the behavior depicted in this figure is somewhat representative of our exhaust temperature measurements, there were significant variations between tests. These variations, as discussed in Section 5.3.6, were caused by the effect of several variables including overall performance of the catalyst, catalyst configuration, and driving conditions (driving cycle).

Figure 5.5 shows the exhaust temperature rapidly increased during the first 300 seconds of the cycle and then stabilized at around 150 °C. During the majority of the second phase of the cycle, the exhaust temperature exhibited an overall downward trend. The sharp temperature decline occurring at around 1,400 seconds corresponds to the end of the second phase and the

beginning of the 10-minute soak period in which the engine of the car was turned off. No temperature data were collected during the soak period.

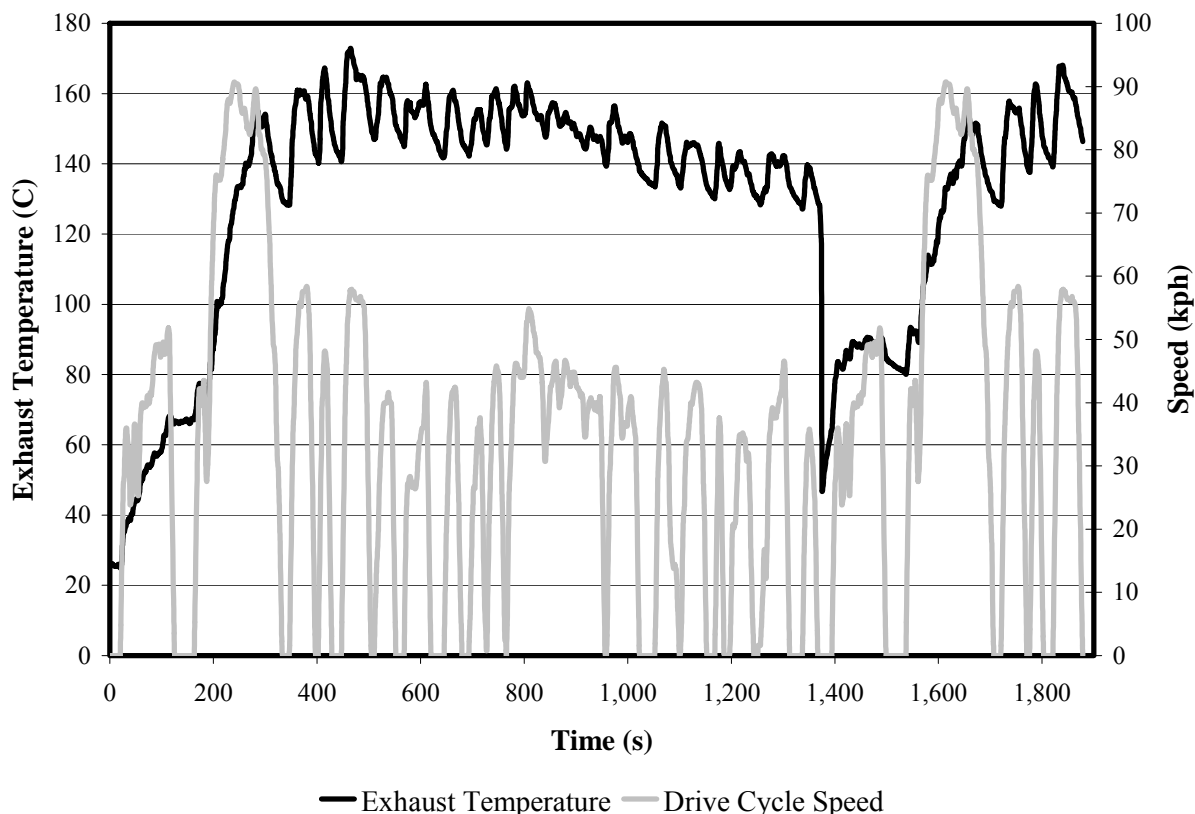


Figure 5.5. Example of an exhaust temperature time series.

The time series depicted in Figure 5.5 also shows a rapid increase in exhaust temperatures at the beginning of the third phase, hot-start emissions, followed by a period of stable reading slightly below 90 °C and another rapid increase to 150 °C, which occurred when the vehicle was subject to the strongest acceleration of the entire cycle. These results suggest a strong correlation between driving conditions and exhaust temperatures.

Figure 5.6 provides additional evidence of the relationship between exhaust temperatures and driving patterns. The highest exhaust temperatures were observed for the more aggressive of the two cycles considered for these analyses. During phase two of the Unified Cycle, consistent with the periods of extreme accelerations that are part of this phase (see Figure 3.12), we measured exhaust temperatures higher than any of those recorded for the UDDS cycle.

Figures 5.7 and 5.8 show the distribution of all of our exhaust temperature measurements. The mean temperature for 160,000 data points was 115 °C and consistent with a normal distribution (due in part to the large number of data points), about 70% of all measurements were within one standard deviation from the mean (115 ± 60).

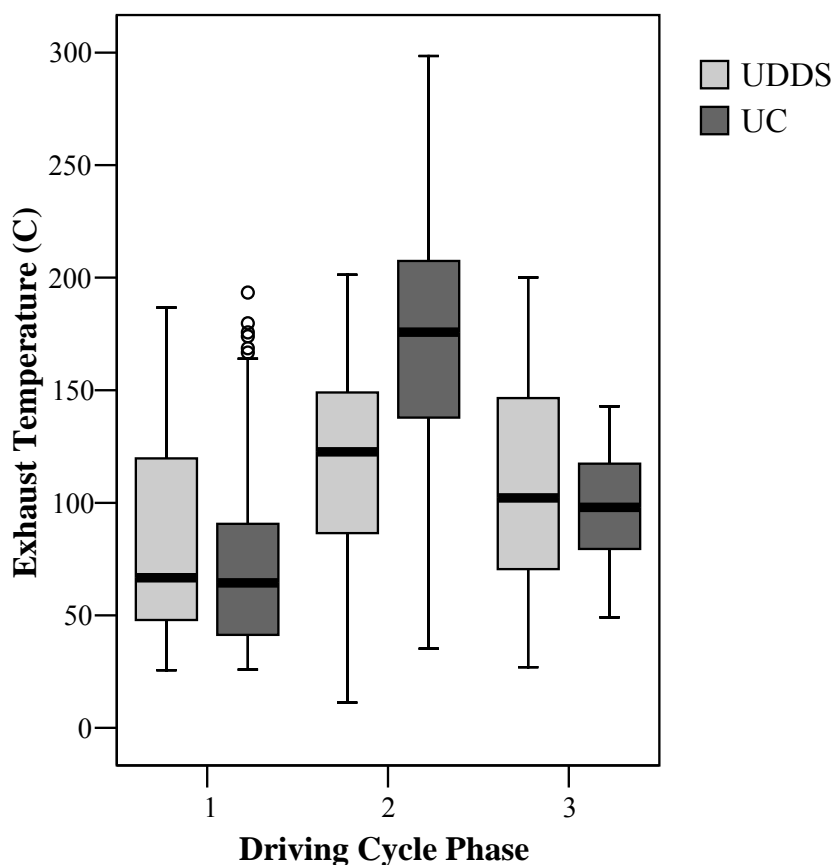


Figure 5.6. Exhaust temperatures by phase and driving cycle.
(See Appendix C for box plot schematic and description)

During the course of our study, we considered the possibility of establishing a correlation between exhaust temperatures and core catalyst temperatures since while exhaust temperatures are relatively easy to measure during in-use vehicle testing programs, catalyst temperatures provide the most relevant information. Such correlation, however, proved to be more complex than expected and was a function of several variables, including vehicle type and catalyst performance (see Section 5.3.4).

5.2.3. Real-Time Concentrations of Exhaust Species

A total of 82 real-time data collection experiments were conducted to determine exhaust concentrations of N₂O, CO₂, and CO using FTIR spectroscopy. During 41 of these experiments, we also collected NO real-time concentration data using the chemiluminescence detector that was part of the CVS system (see Section 3.5.2). This additional method of analysis for NO was necessary since the FTIR technique we used did not have the required sensitivity for nitric oxide.

Figure 5.9 shows an example of a real-time series for N₂O and NO concentrations. These data were obtained from a 1997 light-duty truck tested under the Unified Cycle. As discussed in detail in Section 5.3.3, the behavior of the exhaust species, especially nitrous oxide, varied considerably between experiments. Driving cycle, type of vehicle, and especially catalyst configuration were among the factors determining such behavior.

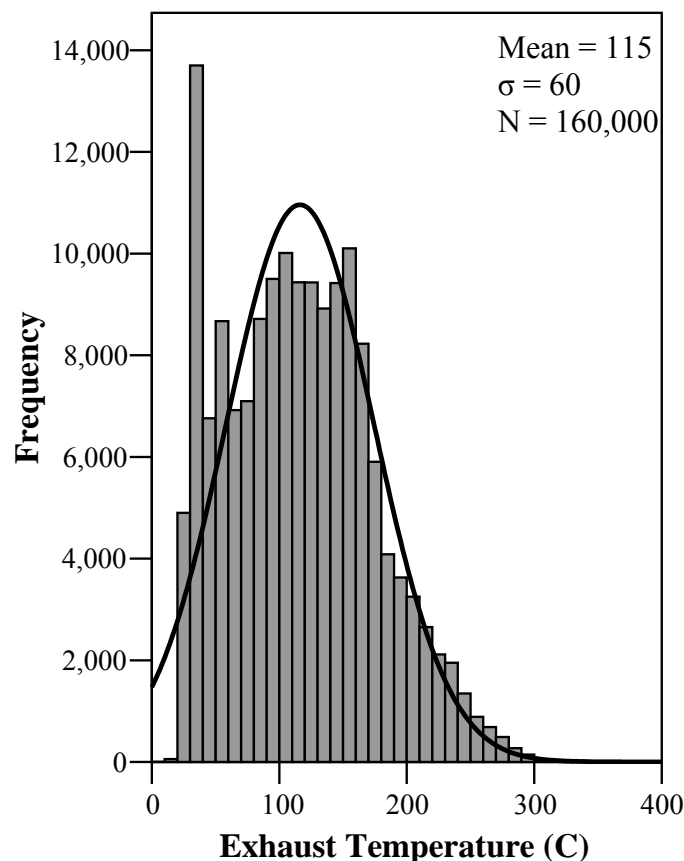


Figure 5.7. Histogram of exhaust temperature measurements.

For the example depicted in Figure 5.9, the highest real-time concentrations of N₂O were observed at around 150 seconds after the beginning of the first and third phase (points A and B). These periods of high nitrous oxide production, as discussed in Section 5.3.4.1, are related to catalyst temperatures below the operational (light-off) temperature but above the minimum temperature required for significant NO_x reduction. The vehicle used for this example exhibited considerable production of N₂O throughout the entire cycle, which was not observed for all tested vehicles.

Although compared to N₂O, nitric oxide concentrations exhibited a more dynamic behavior due to the faster response of the instrument used for these measurements, we observed a high correlation between NO and N₂O concentrations during this specific test. As discussed in Section 5.3.3, the correlation between these two species varied between experiments and was a function of catalyst performance.

Figure 5.10 shows the real-time series for CO₂ and CO concentrations obtained from the same vehicle as above. CO₂ real-time concentration trends were quite similar between experiments since these concentrations are directly proportional to driving cycle speeds. Real-time CO₂ concentrations can be used as a proxy for driving cycle speed during dilute exhaust dynamometer tests. However, since they are also proportional to engine's displacement, the absolute CO₂ concentrations varied between vehicles (see Section 5.3.3).

CO concentration trends varied between experiments and were affected by vehicle type and other variables (see Section 5.3.3). However, for a large number of test vehicles, we observed dilute exhaust CO concentrations similar to those depicted in Figure 5.10, where most of the emissions occurred at the beginning of the cold-start phase (point A). It was also common to observe CO concentration spikes during periods of extreme acceleration, as occurs around 900 seconds (second phase) in the Unified Cycle (point B).

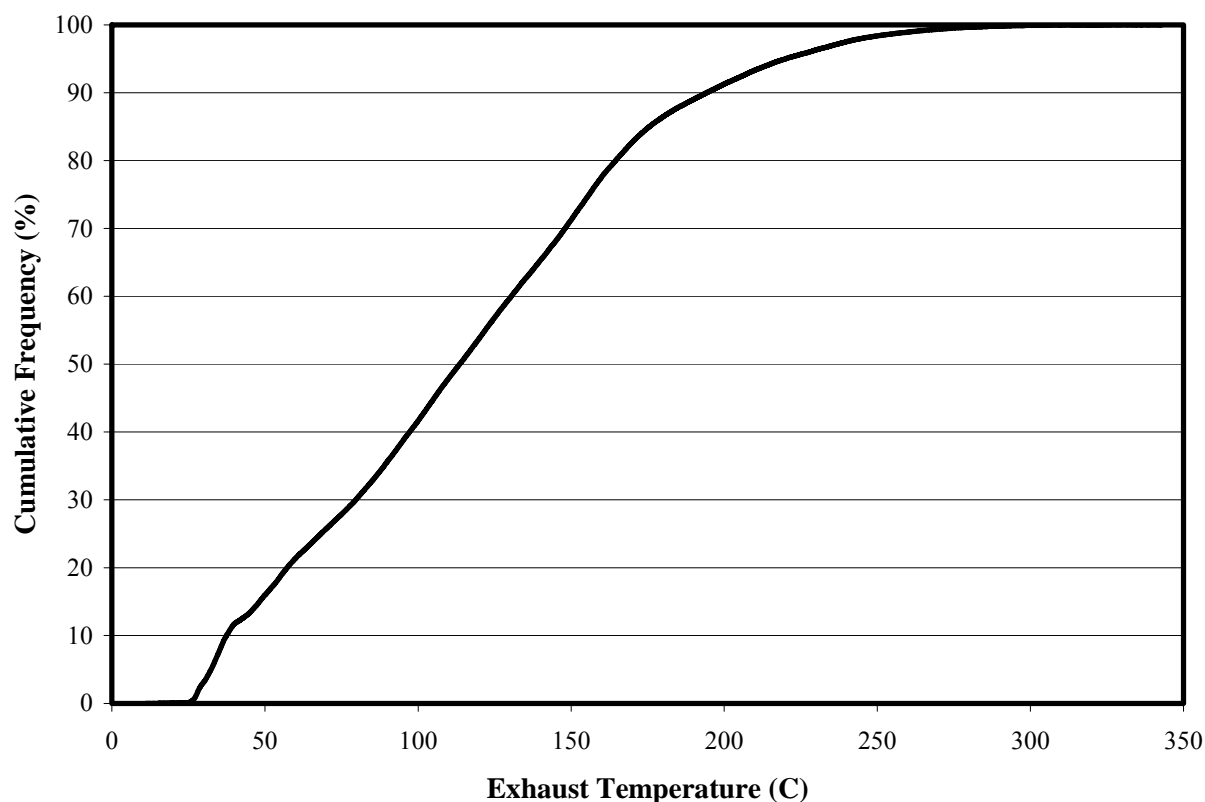


Figure 5.8. Cumulative frequency distribution of exhaust temperature measurements.

Figures 5.11 to 5.14 show the distributions of the real-time pollutant concentration data collected during this part of the study. The distributions for nitrous oxide were determined after removing all data points below ambient background levels (0.3 ppm), which were considered invalid for the real-time dataset. This procedure was based on the assumption that an extremely efficient catalyst could reduce N₂O diluted-exhaust concentrations to close to 0.3 ppm but not lower. In addition, since the real-time data collection method is not a yet a recognized standard analytical method, we did not formally establish its limit of detection nor did we establish the appropriate number of significant figures to be used for the real-time data.

For the 19,000 (out of 23,500) valid data points, the mean dilute exhaust N₂O concentration was 0.70 ppm with a standard deviation of 0.70. The mean dilute exhaust NO concentration was 3.6 ppm with a standard deviation of 8.7 (based on 16,500 valid data points collected with a different instrument that was not used during all real-time experiments). Mean concentrations for CO₂ and CO were 3,300 ppm and 100 ppm, respectively, with standard deviations of 1,800 and 325, respectively. These two populations were comprised of 23,500 data points.

Carbon dioxide was the only species which exhibited an approximate normal distribution. N₂O, NO, and especially CO showed asymmetric and heavily-left skewed data distributions. Dilute exhaust concentrations ranged between 0.30 and 9.4 ppm for N₂O, between 0.1 and 170 ppm for NO, between 400 and 16,000 ppm for CO₂, and between 0.5 and 9,000 ppm for CO.

Figures 5.15 to 5.17 show the scatter plots, incorporating our entire validated dataset, between dilute exhaust concentrations of N₂O and dilute exhaust concentrations of NO, CO, and CO₂. The overall regression coefficients (*r*) were low in all cases: 0.38 between N₂O and NO, 0.30 between N₂O and CO₂, and 0.07 between N₂O and CO since, as discussed in Section 5.3.3, the correlations between the concentrations of these species was heavily influenced by catalyst performance and other variables.

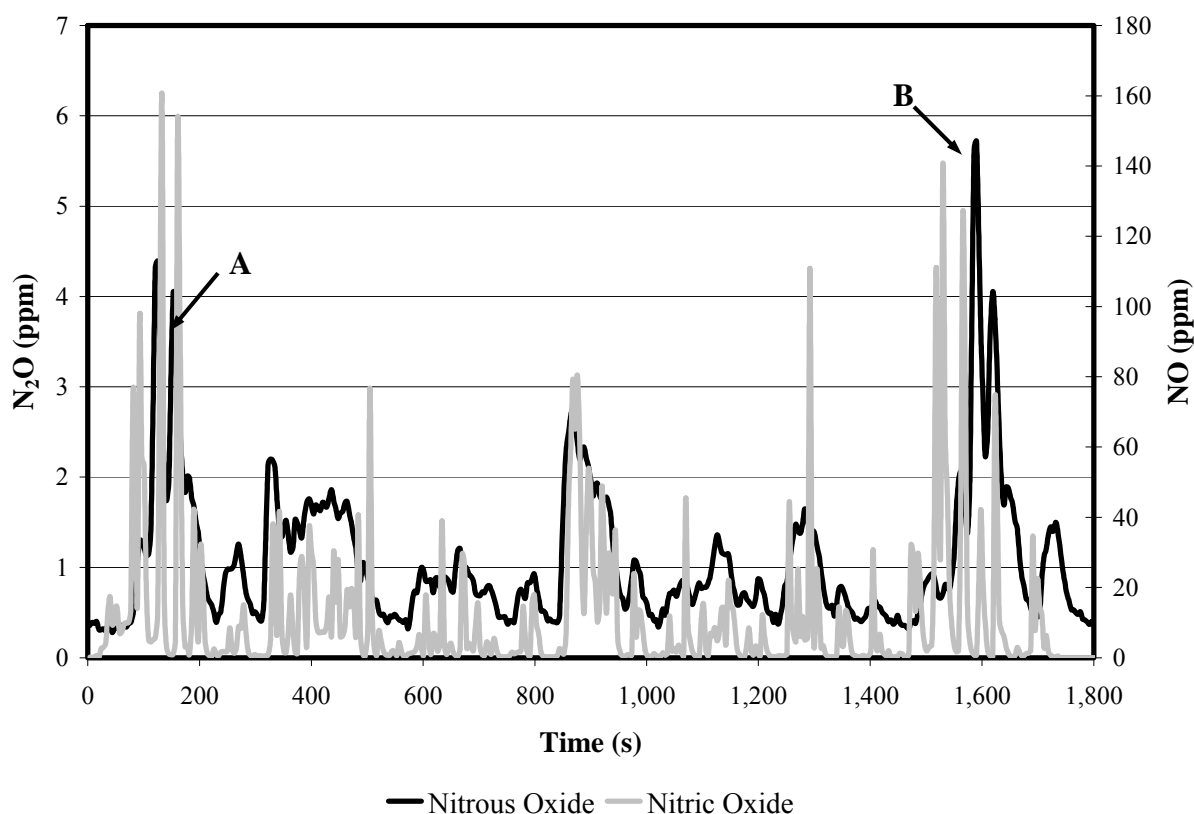


Figure 5.9. Example of a real-time series for N₂O and NO concentrations (Unified Cycle). See text for a discussion of points A and B.

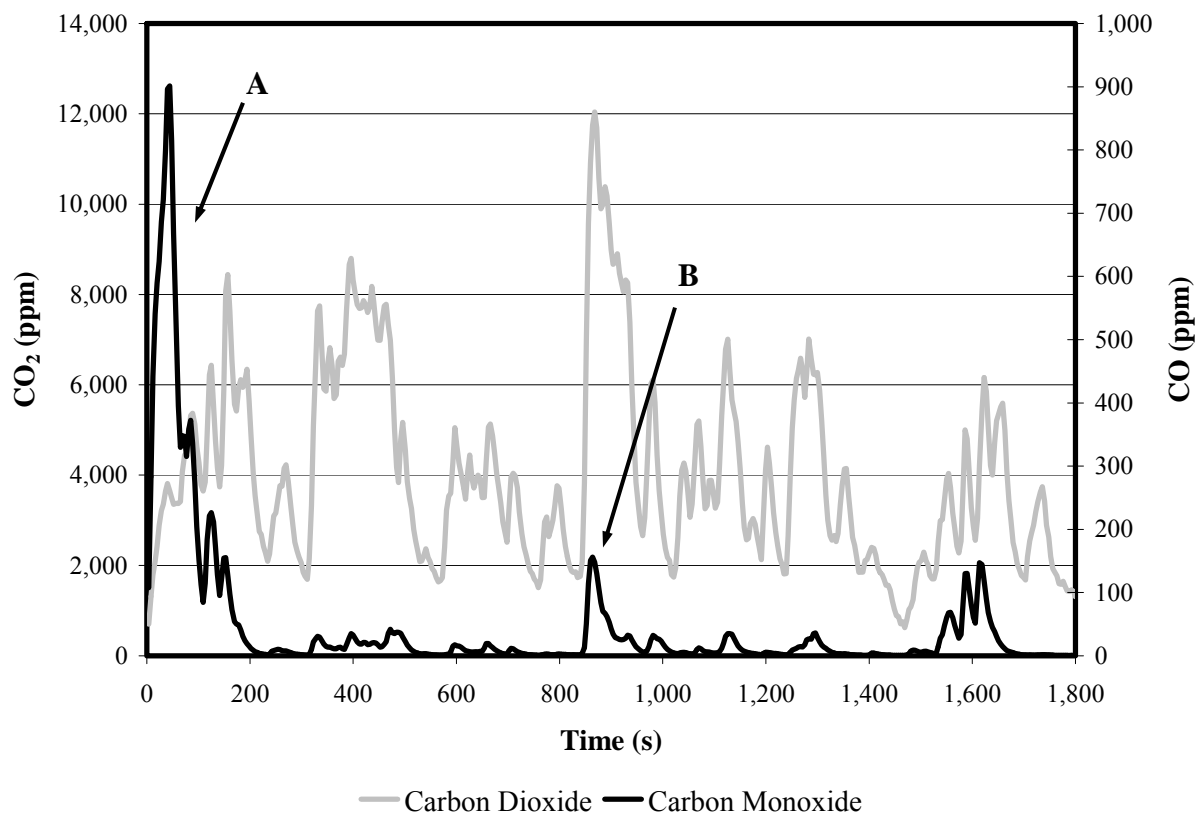


Figure 5.10. Example of a real-time series for CO₂ and CO concentrations (Unified Cycle). See text for a discussion of Points A and B.

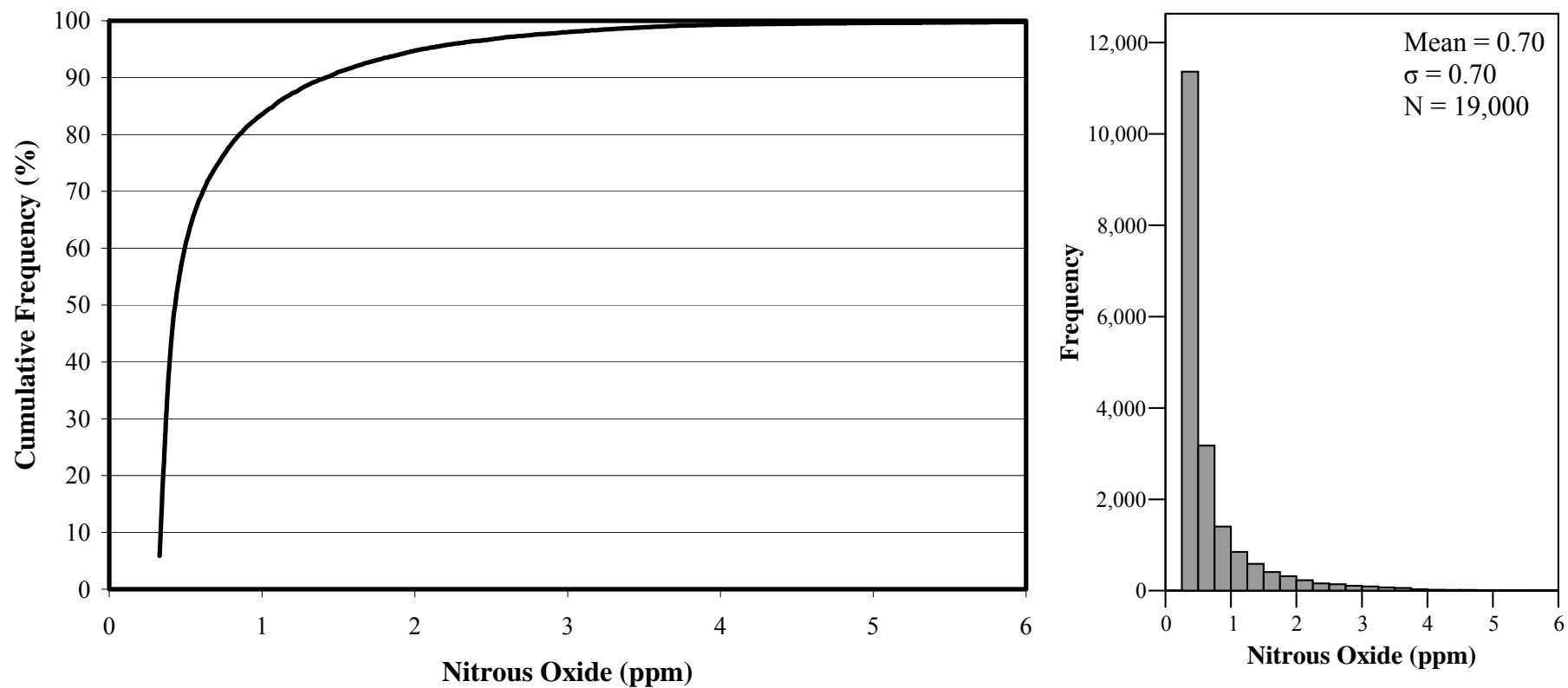


Figure 5.11. Nitrous oxide real-time data distributions.

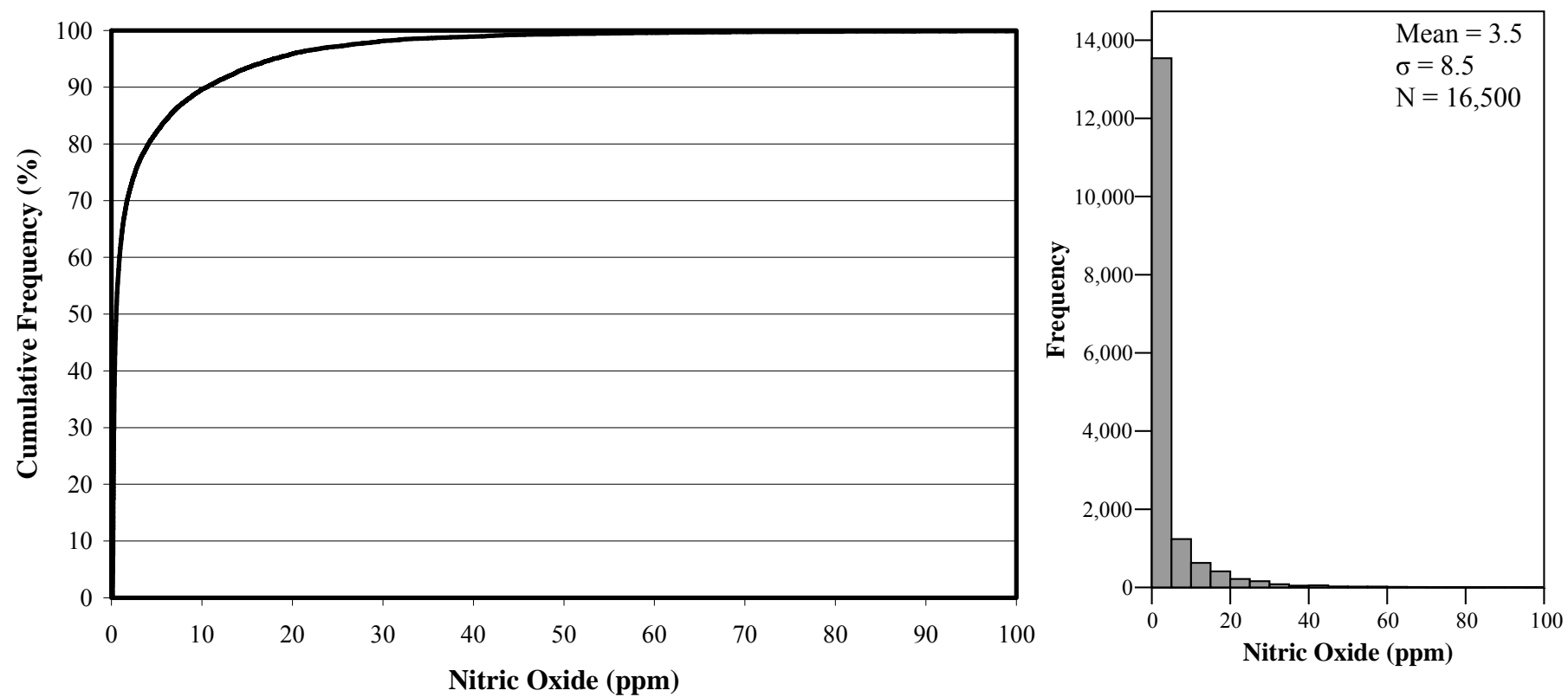


Figure 5.12. Nitric oxide real-time data distributions.

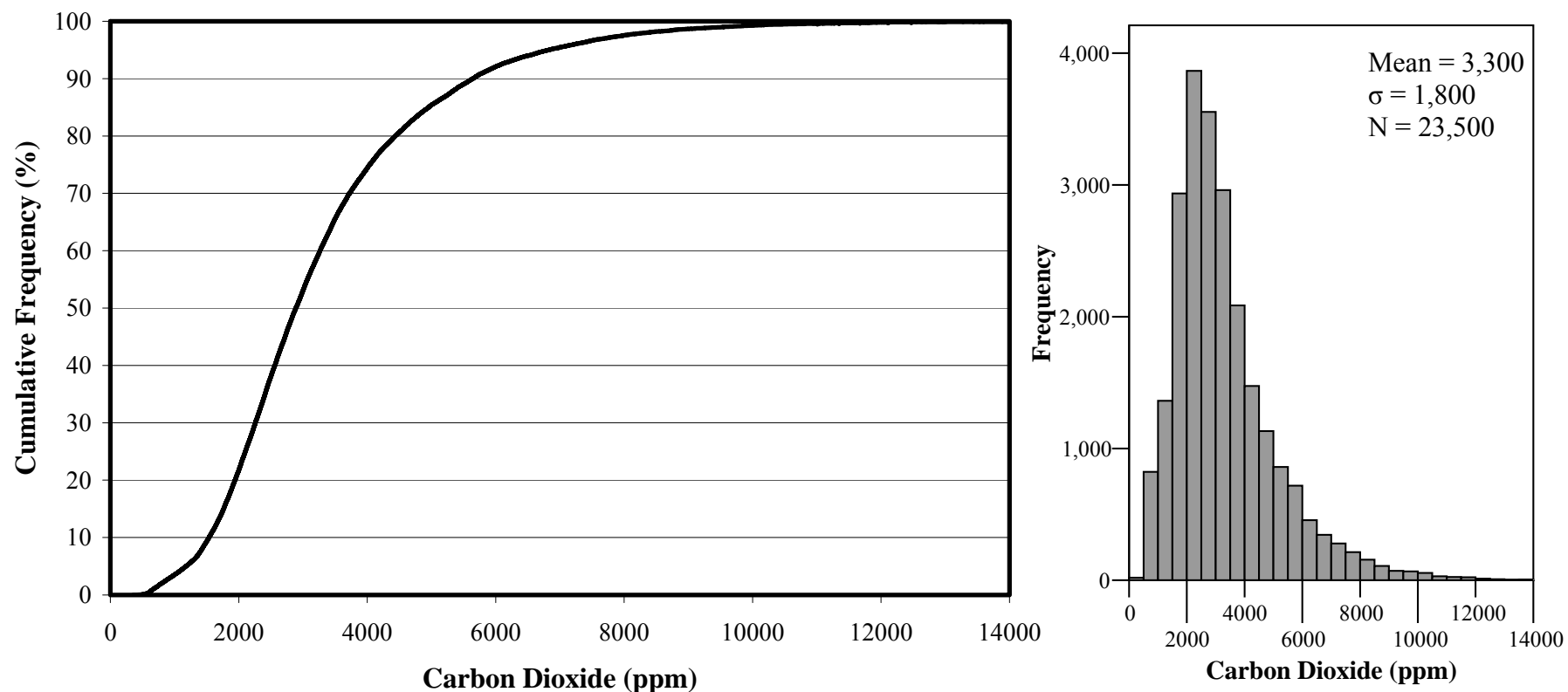


Figure 5.13. Carbon dioxide real-time data distributions.

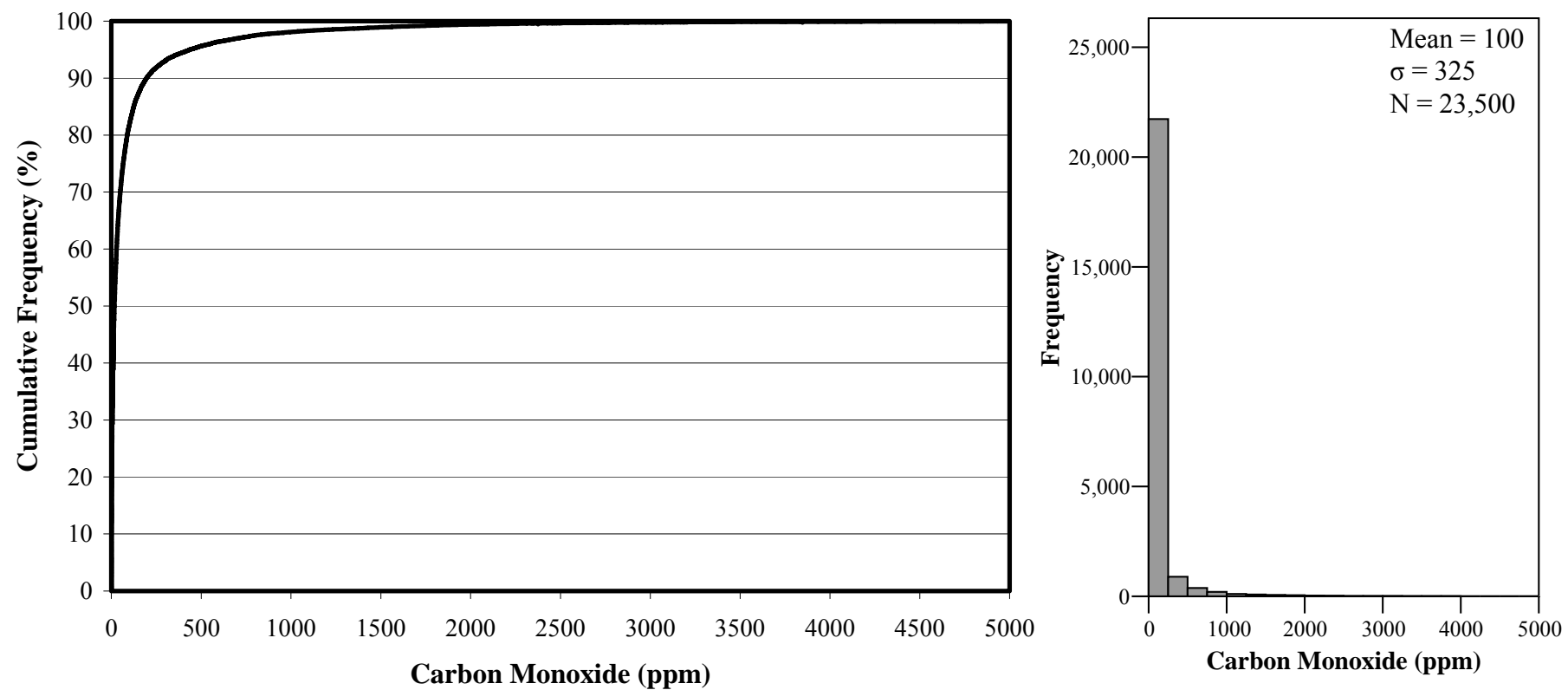


Figure 5.14. Carbon monoxide real-time data distributions.

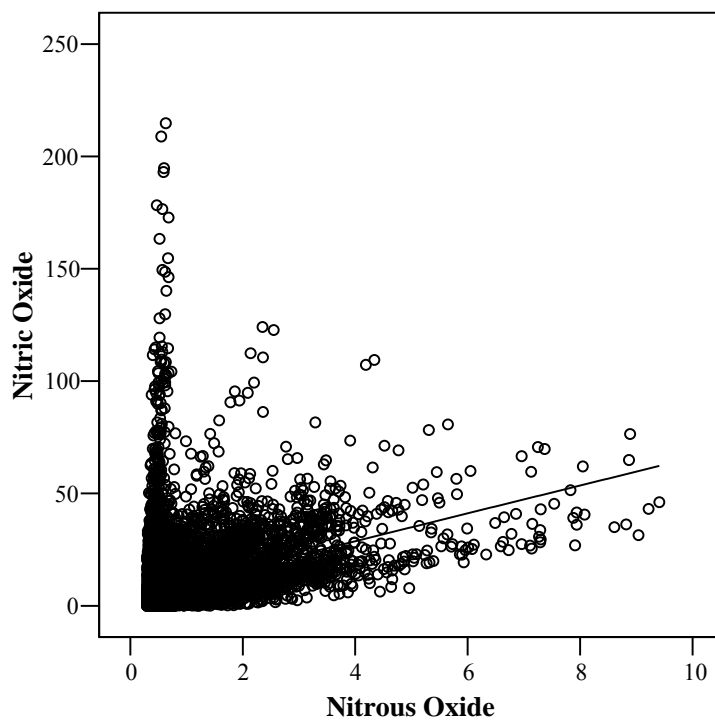


Figure 5.15. Scatter plot between dilute exhaust concentrations of N₂O and NO (ppm).

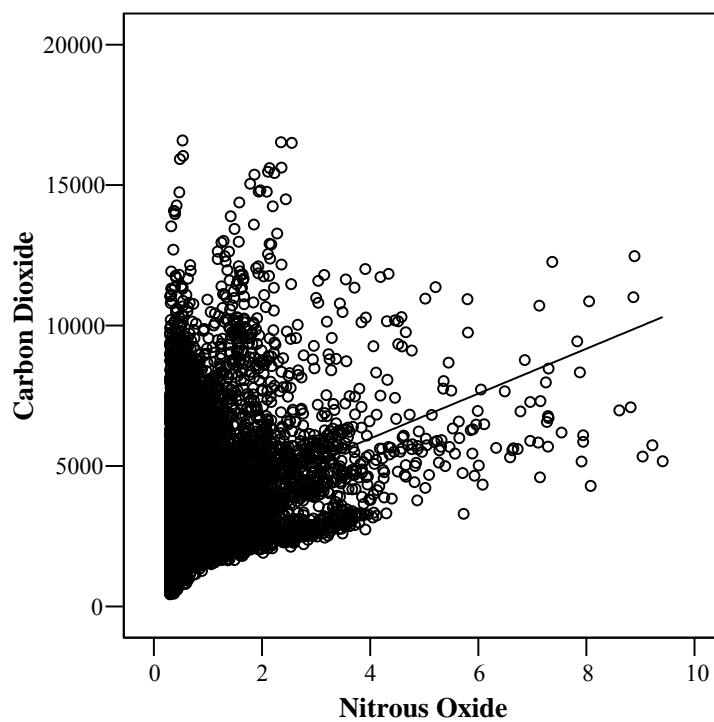


Figure 5.16. Scatter plot between dilute exhaust concentrations of N₂O and CO₂ (ppm).

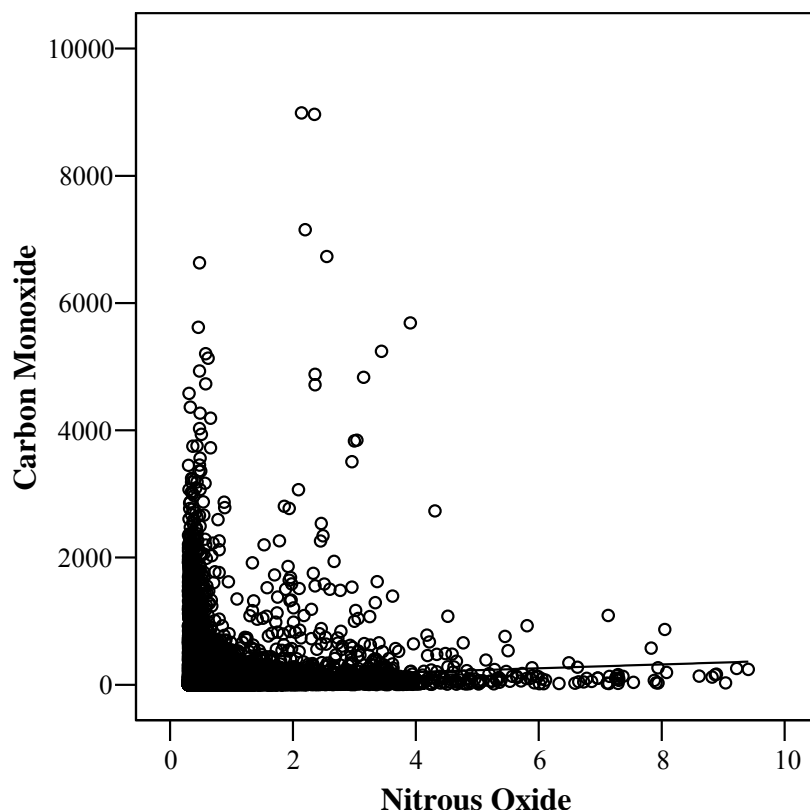


Figure 5.17. Scatter plot between dilute exhaust concentrations of N₂O and CO (ppm).

5.3. Catalyst Study and Detailed Real-Time Analyses

One of the main findings of the real-time preliminary analyses was that our sample of test vehicles could be divided into three categories based on their nitrous oxide emission patterns (low emitters, intermediate emitters, or high emitters). The behavior of vehicles, in terms of their N₂O emissions, within each of the three categories was quite similar, but substantially different from that of the vehicles in the other categories.

Figure 5.18 shows the distribution of N₂O emission factors for all vehicles tested under the UDDS driving cycle and for which integrated samples were collected (see Section 6.2). Low emitters were defined as those vehicles with N₂O emission factors below the 25th percentile (9 mg km⁻¹ for UDDS driving cycle tests). Intermediate vehicles were defined as those vehicles with N₂O emission factors between the 25th and the 75th percentile (9 to 28 mg km⁻¹ for UDDS driving cycle tests). High emitters were defined as those vehicles with N₂O emission factors above the 75th percentile (above the interquartile range).

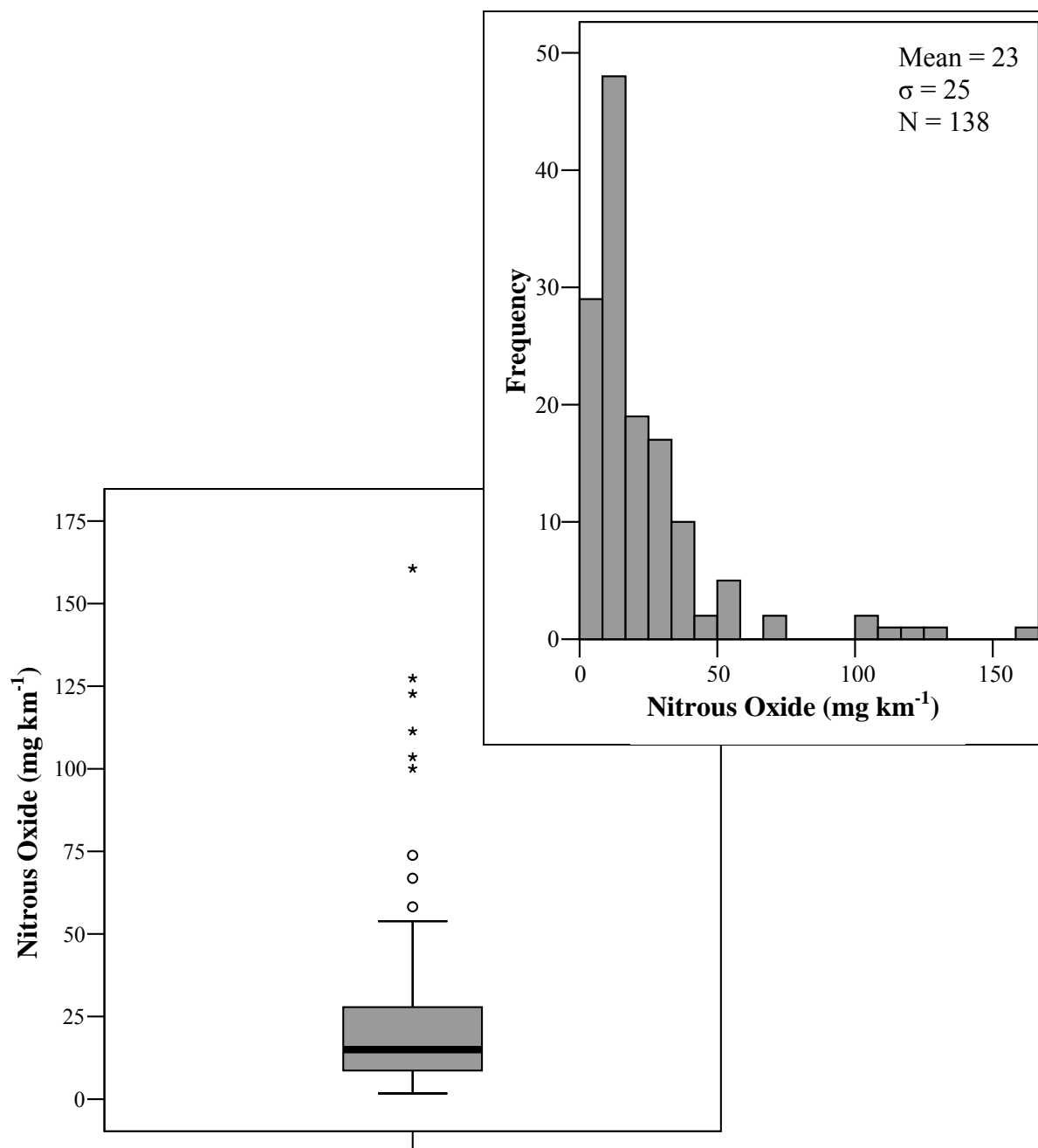


Figure 5.18. Distribution of nitrous oxide emission factors (mg km⁻¹) for vehicles tested under the UDDS cycle (see Appendix C for box plot schematic and description).

Based on these categories, we selected six vehicles (two low emitters, two intermediate emitters, and two high emitters) from the sample of 53 test vehicles used for real-time analyses (see Table 5.1). A total of 35 real-time experiments were conducted with the selected vehicles under a matrix of testing combinations that, as explained in Section 3.4, included three catalyst configurations (empty, in-use, new) and three driving cycles (UDDS, UC, MN₂O). During these

experiments (see Table 5.2), in addition to N₂O dilute exhaust concentrations, we collected concentration data for NO, CO, CO₂, and CH₄, as well as exhaust and core catalyst temperatures.

Table 5.1. Emission factors and categorization of test vehicles.

	Phase 1		Phase 2		Phase 3		E.F (mg km ⁻¹)	Category
	N ₂ O (ppm)	N ₂ O (g)	N ₂ O (ppm)	N ₂ O (g)	N ₂ O (ppm)	N ₂ O (g)		
Vehicle 1	1.13	0.36	0.87	0.41	1.62	0.57	75	High emitter
Vehicle 2	0.41	0.04	0.33	0.01	0.36	0.02	3.5	Low emitter
Vehicle 3	0.67	0.16	0.37	0.04	0.77	0.20	20	Intermediate emitter
Vehicle 4	1.24	0.41	1.02	0.53	1.43	0.48	80	High emitter
Vehicle 5	0.75	0.19	0.36	0.03	0.85	0.23	20	Intermediate emitter
Vehicle 6	0.45	0.06	0.33	0.01	0.36	0.02	4	Low emitter

E.F = Emission factor computed using 40 CFR § 86.144-90. Results obtained from vehicles equipped with in-use catalysts and tested under the UDDS driving cycle.

Table 5.2. Matrix of testing combinations during catalyst study.

	In-use catalyst			Empty catalyst			New catalyst	
	EC cycle	UC cycle	MN ₂ O cycle	EC cycle	UC cycle	MN ₂ O cycle	EC cycle	UC cycle
Vehicle 1	X	X	X	X			X	
Vehicle 2	X	X	X					
Vehicle 3	X	X	X	X	X		X	
Vehicle 4	X	X	X	X	X		X	X
Vehicle 5	X	X	X	X	X		X	X
Vehicle 6	X	X	X	X	X		X	X

5.3.1. Description of Test Vehicles

Vehicle 1 was a 1997, 3.4 liters, Toyota 4 Runner light-duty truck with 130,000 km on its odometer. This vehicle was certified as a TLEV according to California exhaust emission standards and was not equipped with an exhaust gas recirculation (EGR) valve. This light-duty truck was equipped with an aftermarket catalyst (instead of an OEM unit) when recruited for ARB's vehicle surveillance program.

Vehicle 2 was a 2002, 3.5 liters, Nissan Pathfinder light-duty truck with 73,000 km on its odometer. This vehicle was a ULEV according to California exhaust emission standards and was not equipped with an EGR Valve.

Vehicle 3 was a 1998, 1.9 liters, General Motors Saturn passenger car with 105,000 km on its odometer and classified as a TLEV according to California exhaust emission standards. This vehicle was equipped with a computer controlled EGR valve.

Vehicle 4 was a 1992, 4.3 liters, Chevrolet Silverado light-duty truck with 225,000 km on its odometer, classified as a TIER0 vehicle according to California exhaust emission standards, and equipped with an EGR valve controlled by a negative backpressure system.

Vehicle 5 was a 1998, 2.2 liters, Toyota Camry LE passenger car with 160,000 km on its odometer and classified as a LEV according to California exhaust emission standards. This vehicle was equipped with a computer controlled EGR valve and two catalytic converters (pre-catalyst and main catalyst).

Vehicle 6 was a 1998, 1.6 liters, Honda Civic DX passenger car with 140,000 km on its odometer, classified as a LEV according to California exhaust emission standards, and was not equipped with an EGR Valve.

5.3.2. Effect of Removing the Substrate on the Performance of the EGR Valve

As described in Section 3.4, during several of the experiments that were part of this project, vehicles were tested with an empty catalyst (i.e., after removing the catalyst substrate) in an effort to quantify the effect of the catalyst on N₂O emissions. Although no additional testing was conducted to determine EGR valve operation with and without catalyst substrate, qualitative observations of tailpipe pressure, with and without the substrate, indicated only minor changes in exhaust pressure. A different outcome (i.e., significant variation in exhaust pressure) would have affected the performance of the EGR valve system creating a confounding factor that would have made difficult the quantification of the role of the catalytic converter on N₂O emissions.

Two of the vehicles used in this part of the project were equipped with computer controlled EGR valves based on the vacuum applied by a solenoid valve. In these cases, the engine's computer determined the EGR valve operation based on a number of parameters including engine load, manifold vacuum, and air-to-fuel ratio. Since exhaust backpressure was only one of the parameters measured to control the EGR function, slightly lower exhaust backpressures, resulting from the lack of substrate in the empty catalyst configuration, had a minimal effect on the overall performance of the EGR valve for these vehicles.

One of the vehicles used in this part of the project was equipped with a negative backpressure EGR valve in which the system was controlled by vacuum lines to the intake manifold and exhaust backpressure sensors. If exhaust backpressure was low, air was flowed into the EGR vacuum line reducing the vacuum signal and preventing the EGR valve operation. This in turn created an accumulation of exhaust backpressure until the diaphragm in the pressure sensor blocked the air flow and allowed EGR operation. An analog pressure meter and visual inspection of the EGR valve during engine operation confirmed the EGR valve was opening and

closing, reflecting a normal operation of the EGR system for this vehicle during empty-catalyst testing.

Three of the vehicles used in this part of the project were not equipped with EGR valves to control NO_x emissions. In these cases, variable cam (valve) timing, catalytic conversion, and retarded spark timing were used to control emissions of nitrogen oxides. The variable valve timing (VVT) in these vehicles acted as a de-facto exhaust gas recirculation system within the cylinders in which the exhaust valve stayed open during a portion of the intake cycle (valve overlap) allowing exhaust gas to enter the fuel-air mixture. The oxygen sensors placed after the catalyst on these three vehicles may have controlled the air-to-fuel ratio differently depending upon whether the substrate of the catalyst was present. Testing for this effect, which we assume was minimal, was beyond the scope of our project.

5.3.3. *Real-Time Emissions*

Figure 5.19 depicts typical real-time dilute exhaust N₂O concentration measurements from vehicles tested under the UDDS cycle. High emitting vehicles exhibited two periods of high N₂O production at about 250 seconds after the beginning of phases one and three (points A and B). For high emitters tested under the UDDS cycle, N₂O dilute exhaust concentrations were generally highest during the third phase. These vehicles also exhibited significant N₂O production during the entire duration of the driving cycle.

Intermediate N₂O emitters also exhibited two periods of high production of N₂O shortly after the beginning of phases one and three. However, for these types of vehicles, the periods of high N₂O production occurred earlier (about 100 seconds after the engine was started) and the observed concentrations were smaller than those for high emitting vehicles (points C and D). In addition, intermediate emitters only produced small amounts of N₂O during the hot stabilized mode (second phase).

Low emitting vehicles exhibited a small and brief period of N₂O production at about 75 seconds after the beginning of the cold-start phase (Point E). For these vehicles, observed N₂O dilute exhaust concentrations were close to ambient levels for most of the remainder of the driving cycle.

The differences in timing and magnitude for N₂O concentration spikes between vehicle categories were related to the time required for the catalysts to reach their operational temperatures. Catalyst warm-up periods for high emitting vehicles were much longer than for low emitting vehicles. The effect of catalyst temperature on nitrous oxide emissions is further discussed in Section 5.3.4.

Figure 5.20 shows the real-time dilute exhaust NO concentration measurements from the same vehicles for which N₂O data are given in Figure 5.19. High N₂O emitters were also high NO emitters. For these vehicles, we observed sharp NO dilute exhaust concentration spikes during the entire driving cycle, following patterns similar to those observed for N₂O concentrations (see Figure 5.19).

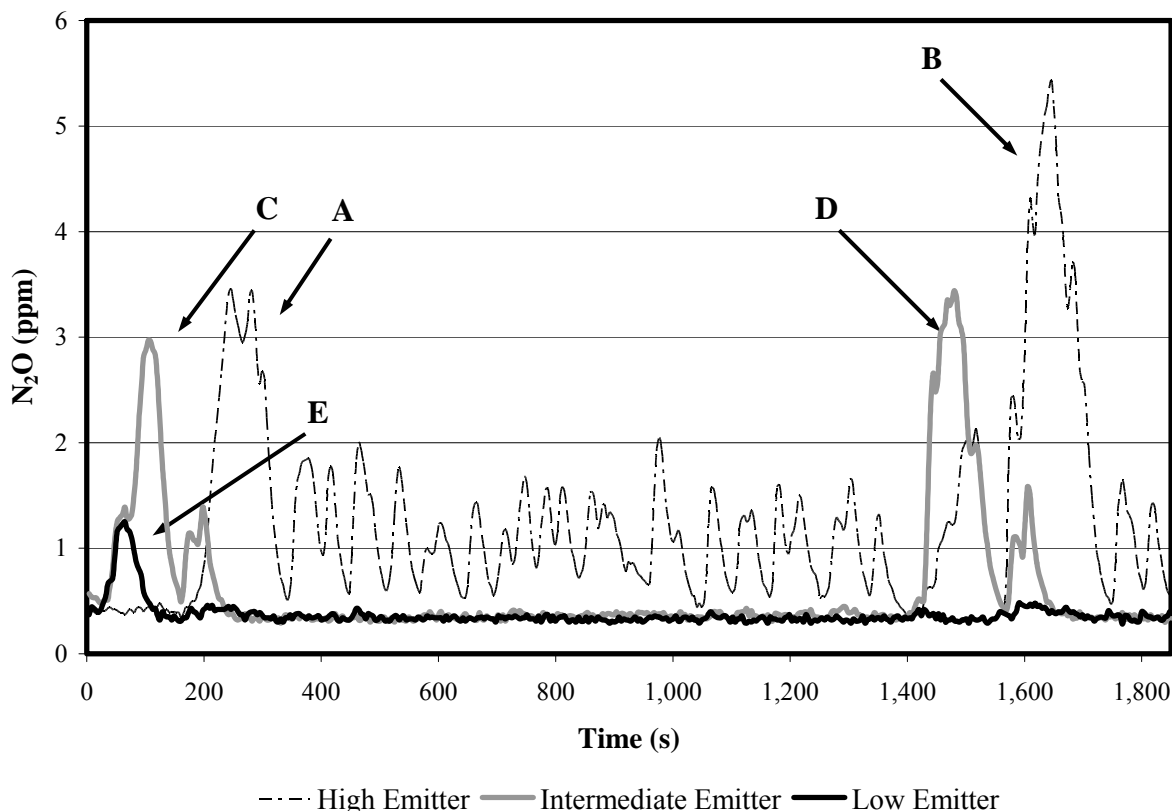


Figure 5.19. Real-time N₂O concentrations by vehicle category (results obtained from vehicles equipped with in-use catalysts and tested under the UDDS cycle). See text for explanation of points A-E.

NO dilute exhaust concentration patterns for intermediate emitters were also consistent with the N₂O concentration patterns for intermediate emitters. Several NO concentration spikes were observed during the cycle and they occurred at the same time at which N₂O concentration spikes were observed. NO emissions for intermediate emitters were lower than NO emissions for high N₂O emitters.

Low N₂O emitters exhibited low NO emissions. For these vehicles, we observed a sharp concentration spike at the beginning of the cold-start phase. Dilute exhaust NO concentrations for low N₂O emitters were in the single-digit parts-per-million range for the vast majority of the driving cycle.

Figure 5.21 shows the real-time dilute exhaust CO₂ concentration measurements from the same vehicles involved in figure 5.19 and 5.20. As expected, dilute exhaust CO₂ concentration patterns were almost identical for all cases since, as discussed earlier, these concentrations are mostly related to driving cycle speeds. The relatively small differences in the concentration values are explained by the vehicles' engine displacement. Vehicles with larger engines produced higher CO₂ emissions. The high N₂O emitter in Figure 5.21 was a 4.3 liters light-duty truck, the intermediate emitter was a 2.2 liters passenger car, and the low emitter was a 1.6 liters passenger car. Therefore, diluted CO₂ concentrations followed the pattern of high, intermediate,

and low emitting vehicles due to the engine size and not necessarily because high N₂O emitters are also high CO₂ emitters (in contrast to the correlation between NO and N₂O emissions).

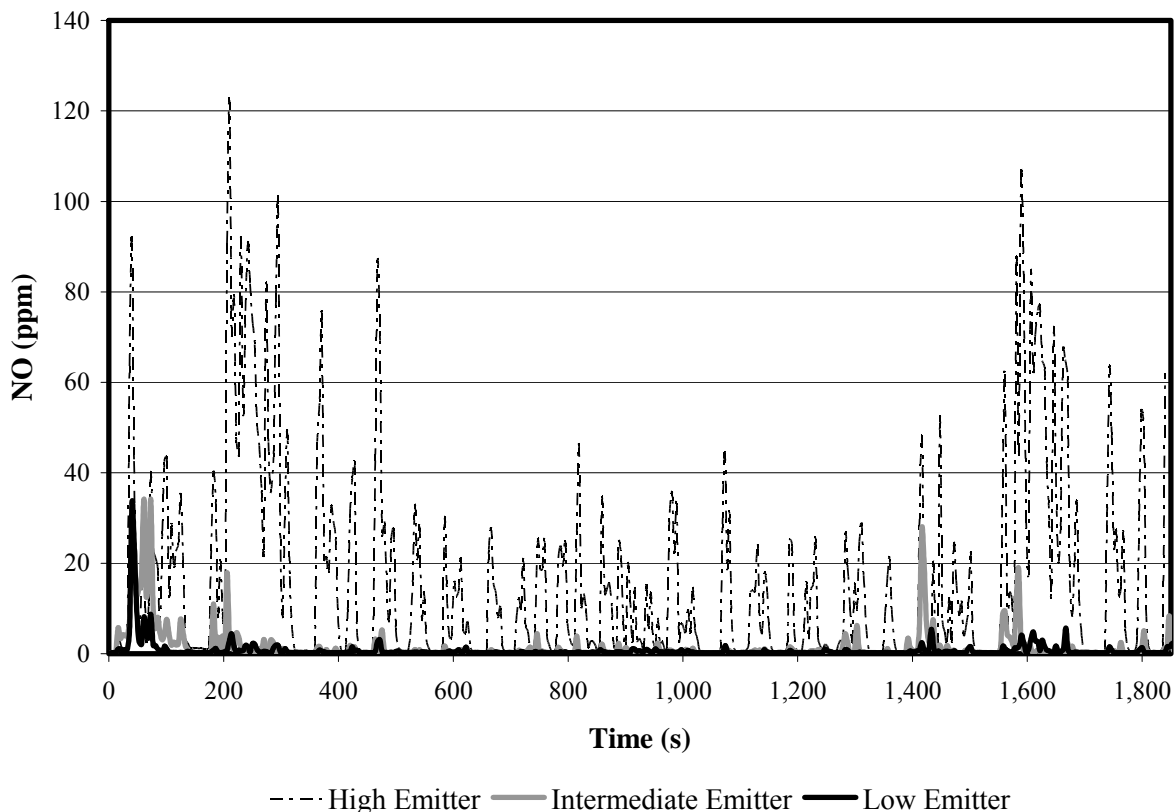


Figure 5.20. Real-time NO concentrations by vehicle category (results obtained from vehicles equipped with in-use catalysts and tested under the UDDS cycle).

Figure 5.22 shows the real-time dilute exhaust CO concentration measurements from the vehicles discussed above. High N₂O emitters were also high CO emitters and exhibited CO concentration spikes throughout the entire driving cycle, following patterns similar to those observed for N₂O and CO₂ concentrations when testing high emitting vehicles. These results suggest a correlation between acceleration patterns and emissions of CO and N₂O. This correlation, however, was significant only for high N₂O emitters. Low and intermediate N₂O emitters exhibited lower CO emissions compared to high N₂O emitters. Contrary to observations for NO dilute exhaust concentrations, low N₂O emitters exhibited higher CO emissions than intermediate N₂O emitters.

Figure 5.23 shows the real-time dilute exhaust CH₄ concentration measurements from the vehicles discussed above. High N₂O emitters were also high CH₄ emitters. These vehicles exhibited similar dilute exhaust N₂O and CH₄ concentrations patterns. Intermediate N₂O emitters exhibited lower CH₄ emissions than high N₂O emitters and higher CH₄ emissions than low N₂O emitters.

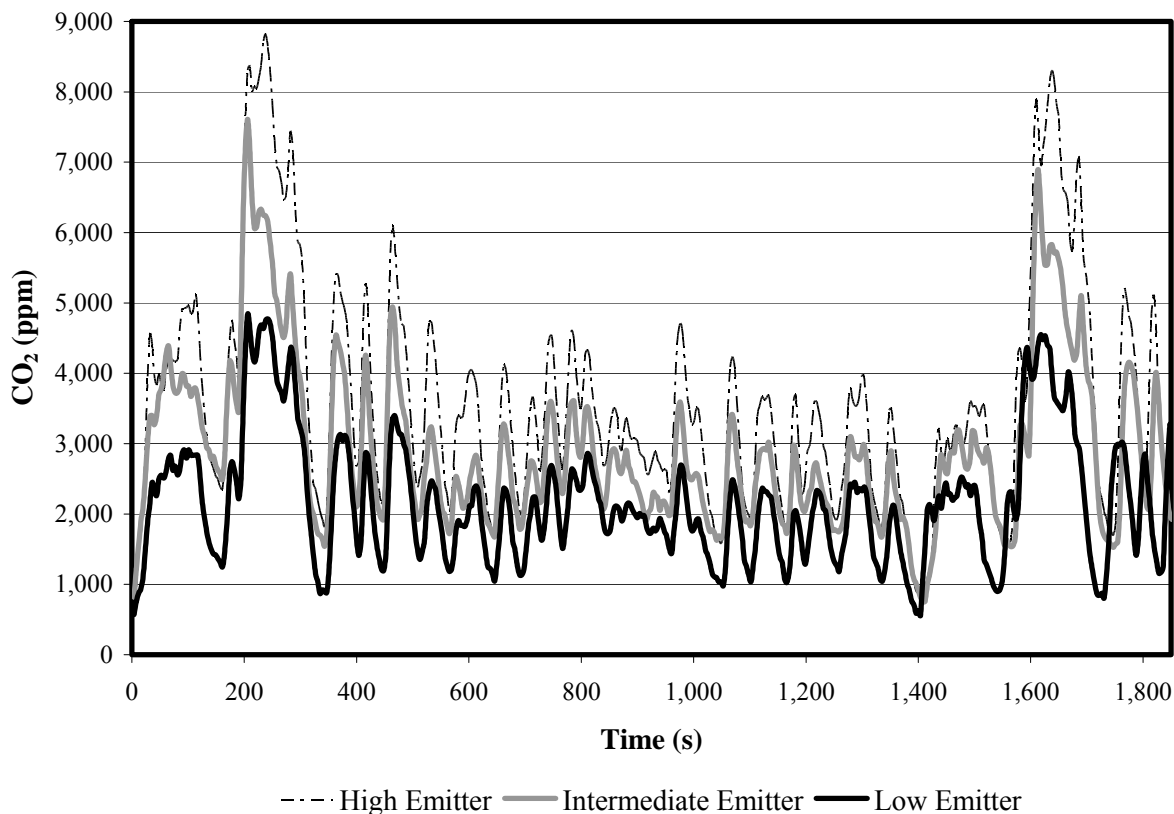


Figure 5.21. Real-time CO₂ concentrations by vehicle category (results obtained from vehicles equipped with in-use catalysts and tested under the UDDS cycle).

Figure 5.24 depicts the correlations between dilute exhaust N₂O concentrations and dilute exhaust CO₂, NO, CH₄, and CO concentrations when testing a high N₂O emitter vehicle under the UDDS cycle. For these types of vehicles, as mentioned before, N₂O is produced during the majority of the cycle and, with the exception of the beginning of the cold-start phase where N₂O production is not significant until about 200 seconds after the engine is started, N₂O and CO₂ concentrations followed similar patterns ($r^2 = 0.65$).

For high emitting vehicles, the correlation between N₂O and NO dilute exhaust concentrations was also relatively high and we observed N₂O and NO concentration spikes occurring at similar times. The chemiluminescence detector used to determine NO concentrations had a time response of one second, compared to the FTIR's time response of about 4 seconds (see Figure 5.24). After applying a 4-second moving average to the NO concentration data, we determined a correlation coefficient of 0.40 between NO and N₂O real-time dilute exhaust concentrations for high N₂O emitter vehicles.

The time series presented in Figure 5.24 also indicate dilute exhaust CO and CH₄ concentrations followed somewhat similar patterns to dilute exhaust N₂O concentrations when testing high emitters. For CO and CH₄, however, there were segments (other than the beginning of the cold-start phase) in which their concentration time series did not track the real-time N₂O diluted concentrations. In particular, we observed a time-delay between N₂O and CH₄

concentrations and between N₂O and CO concentrations. Methane and carbon monoxide concentration spikes tended to occur slightly earlier than corresponding nitrous oxide concentration spikes. This phenomenon, explained by the kinetics of the catalytic converter, affected the correlation coefficients between concentrations of N₂O and CH₄ and between concentrations of N₂O and CO, 0.15 and less than 0.10, respectively.

As discussed earlier, for intermediate and low emitter vehicles, most of their nitrous oxide emissions were produced during specific and relatively short segments of the driving cycles. In these cases, especially for low emitting vehicles, real-time N₂O dilute exhaust concentrations were close to ambient levels during the majority of the cycles, resulting in quite low correlations between real-time concentrations of nitrous oxide and real-time concentrations of other exhaust species.

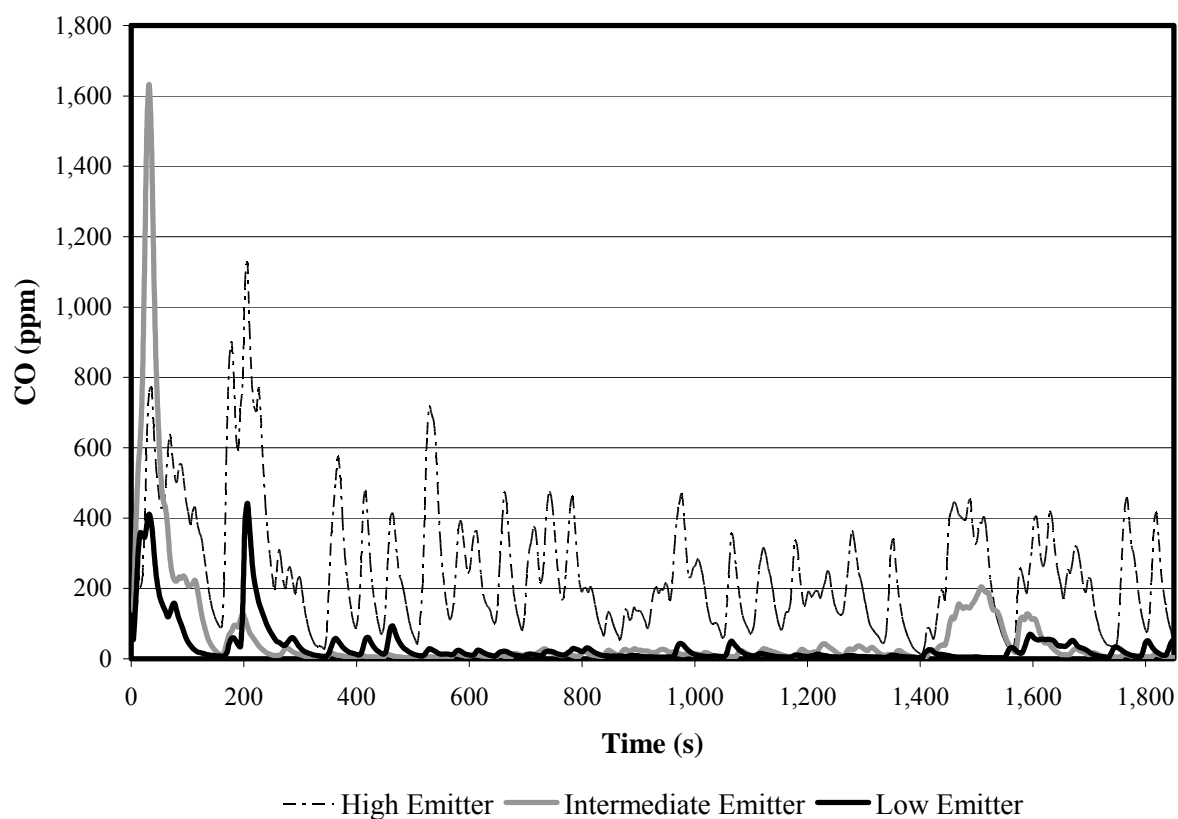


Figure 5.22. Real-time CO concentrations by vehicle category (results obtained from vehicles equipped with in-use catalysts and tested under the UDDS cycle).

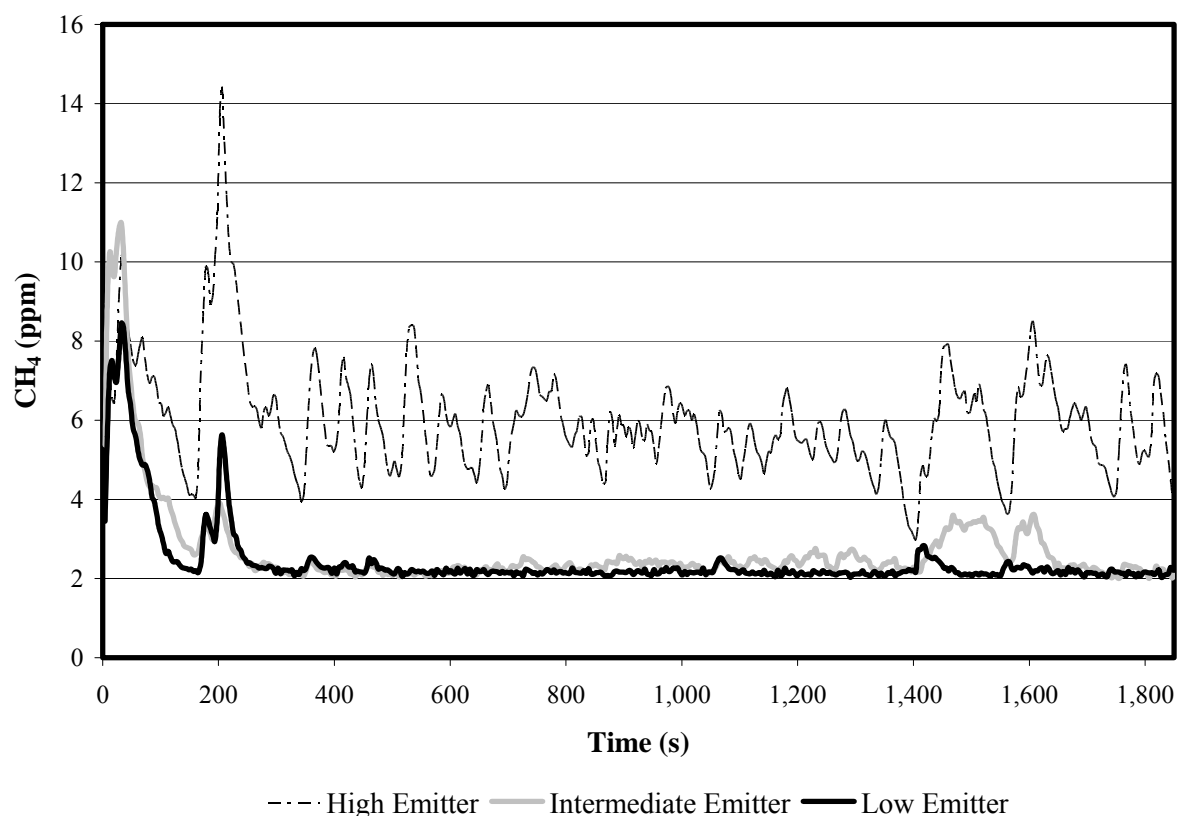


Figure 5.23. Real-time CH₄ concentrations by vehicle category (results obtained from vehicles equipped with in-use catalysts and tested under the UDDS cycle).

5.3.4. *Effect of Catalyst Temperature*

In this section, we provide quantitative measures for the relationship between catalyst temperatures and N₂O emissions from light-duty vehicles. We start our discussion, however, by determining the correlation between exhaust temperatures (measured at the mixing tee) and core catalyst temperatures (measured inside the catalytic converter). As mentioned in Section 5.2.2, routine measurements of exhaust temperatures can be easily implemented in in-use testing programs while measurements of catalyst temperatures, the most relevant information, is not generally a feasible alternative given the necessity of drilling a hole in the catalyst to install the measuring device.

Figure 5.25 shows the scatter plot for catalyst and exhaust temperature measurements conducted on vehicles equipped with in-use catalysts and tested under the Unified Cycle. Although our sample size was substantial, the correlation between these measurements was limited ($r^2 = 0.35$, $N = 10,400$) leading to the conclusion that exhaust temperatures are not an appropriate proxy for catalyst temperatures.

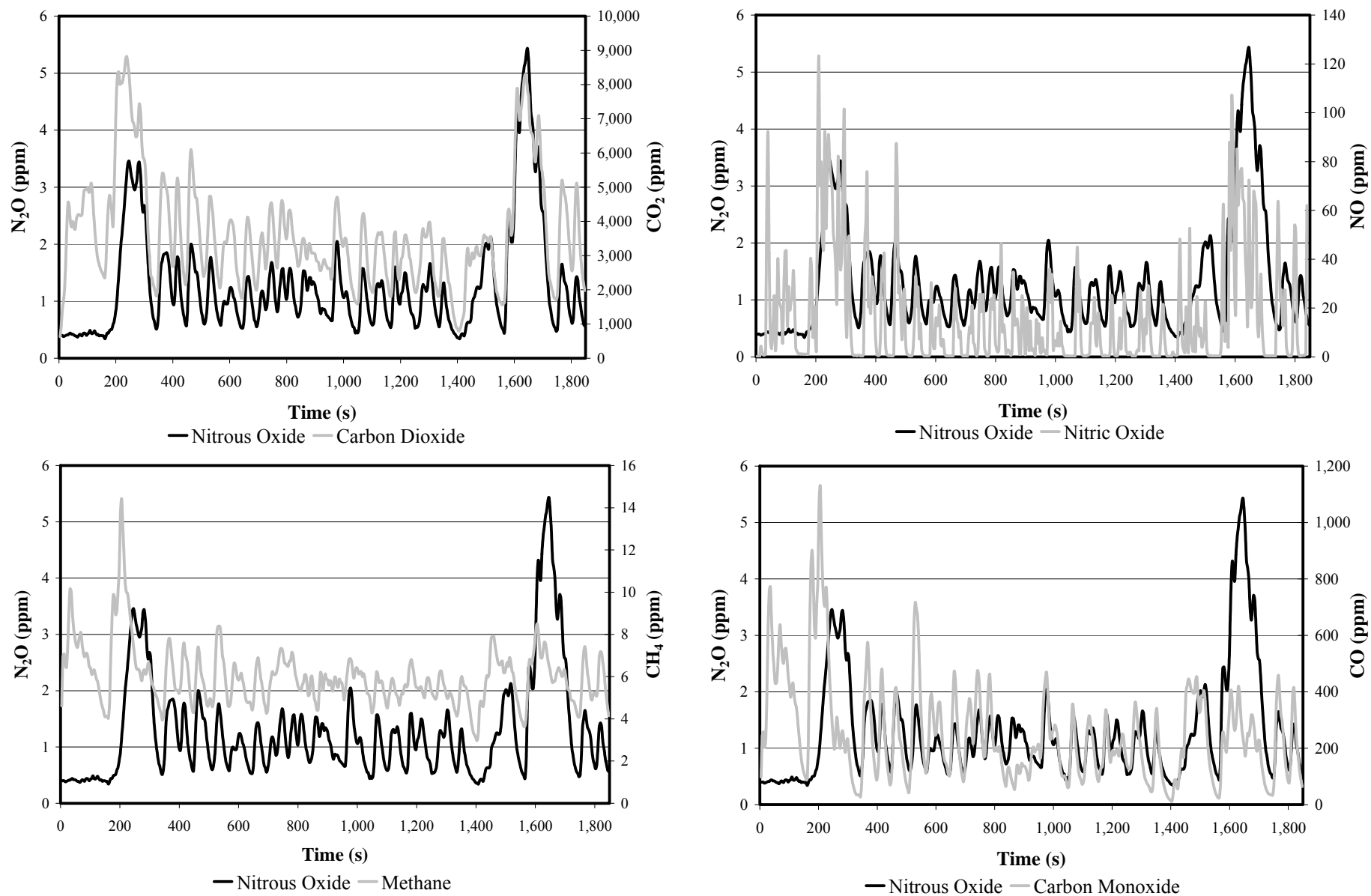


Figure 5.24. Real-time N₂O, CO₂, NO, CH₄, and CO concentrations for a high N₂O emitter vehicle (UDDS cycle).

Figure 5.26 shows an example of typical real-time exhaust and catalyst temperatures and explains the limited correlation between these measurements. These data, obtained from an intermediate N₂O emitter (equipped with its in-use catalyst) tested under the UDDS cycle, show exhaust and catalyst temperatures start tracking each other 500 seconds after the start of the first phase and about 250 seconds after the start of the third phase. Based on these results, it appears the temperature inertia of the material of which the mixing tee, the tailpipe tip, and the junctions between the tailpipe and the mixing tee are built has to be overcome before exhaust temperatures can provide useful information. Given the time required between vehicle tests (to flush the dilution tunnel and to analyze the gas samples collected in the Tedlar bags that are part of the CVS unit), this limitation appears unavoidable under the current protocol for emissions testing.

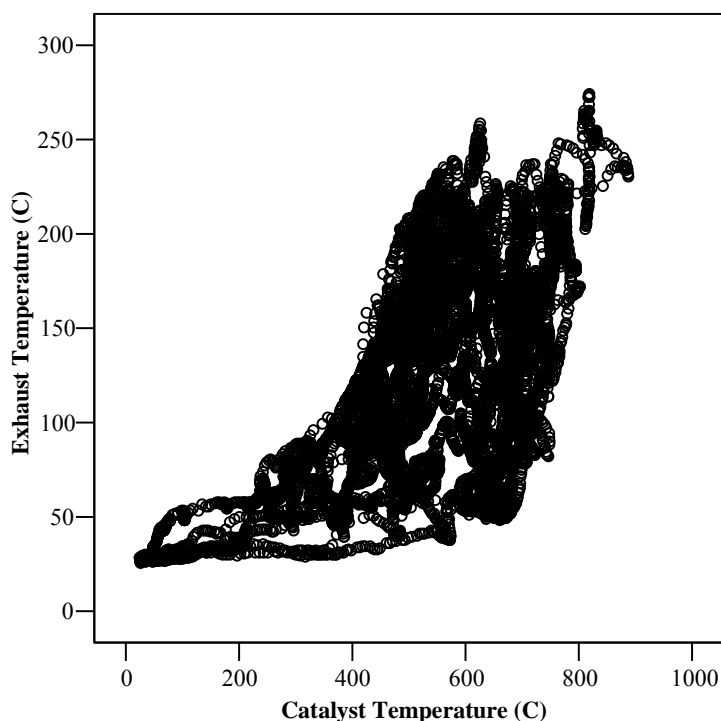


Figure 5.25. Correlation between exhaust and catalyst temperatures (results obtained from vehicles equipped with in-use catalysts and tested under the Unified Cycle).

5.3.4.1. Core Catalyst Temperatures and Nitrous Oxide Emissions

Figure 5.27 depicts the distribution of all catalyst temperature measurements conducted in vehicles equipped with in-use catalysts and tested under the UC and UDDS cycle. Mean catalyst temperature for this sample was close to 550 °C and 97.5 % of all data points were above 90 °C.

Figure 5.28 shows typical real-time catalyst temperatures for high and low emitting vehicles (equipped with their in-use catalyst) tested under the Unified Cycle. The low N₂O emitter vehicle exhibited a rapid increase in catalyst temperatures, reaching values above 550 °C in less than 100 seconds. The mean catalyst temperature for this vehicle was 650 °C. For the high N₂O emitter vehicle, catalyst temperatures after 500 seconds reached the 450 °C limit. The mean catalyst temperature for this vehicle was 400 °C.

As discussed in Section 2.4, at high catalyst temperatures, NO is directly reduced to N₂ while at lower temperatures N₂O is an intermediate product during the catalytic reduction of NO. Our results confirm that an ineffective performance by the catalytic converter, in terms of its inability to quickly reach high temperatures, causes elevated emissions of nitrous oxide. This is also consistent with the finding that high N₂O emitter vehicles (i.e., vehicles equipped with underperforming catalysts) also exhibited elevated emission of other exhaust species, including NO, CO, and CH₄.

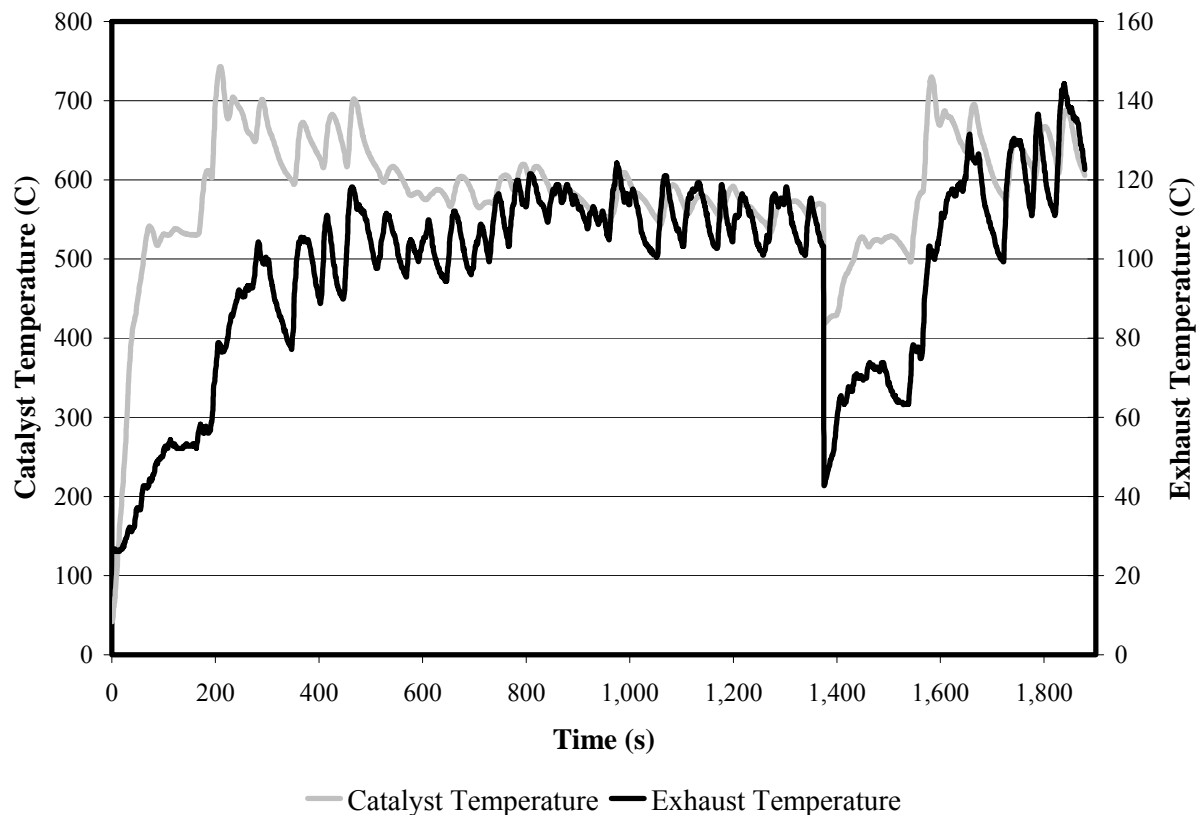


Figure 5.26. Typical real-time exhaust and catalyst temperatures for an intermediate emitter tested under the UDDS cycle.

Figures 5.29 and 5.30 show typical real-time N₂O concentrations and catalyst temperatures for high and low emitting vehicles, respectively. From this point on, we focus our analyses on high and low emitting vehicles. As shown above, intermediate emitters represent a middle-ground between these two cases.

Figure 5.29 was divided in 7 segments based on the N₂O emission patterns for the high N₂O emitter and their relationship with catalyst temperatures. In the first segment, N₂O production had not yet started due to low catalyst temperatures. We have mentioned catalytic production of N₂O is related to low temperatures, however, according to our results, if the catalyst temperature was below 120 °C, there was no significant reduction of nitric oxide and therefore no N₂O was produced. During this period, the vehicle behaved as if it was not equipped with a catalytic converter.

Segment two was the period with the highest N₂O emissions during a Unified Cycle applied to a high N₂O emitting vehicle. Catalyst temperatures were high enough to start the process of NO reduction but at the same time they were not high enough to prevent the formation of nitrous oxide as an intermediate.

Segment three exhibited lower N₂O emissions, compared to segment two, since catalyst temperatures were able to reach values around 480 °C. In segment four, around 900 seconds after the start of the test, the Unified Cycle exhibited its highest accelerations (see Figure 3.12) promoting the formation of nitrous oxide. These results demonstrate N₂O is a function of both acceleration patterns and catalyst temperatures when testing high emitting vehicles, an issue that is further discussed in Section 5.3.6

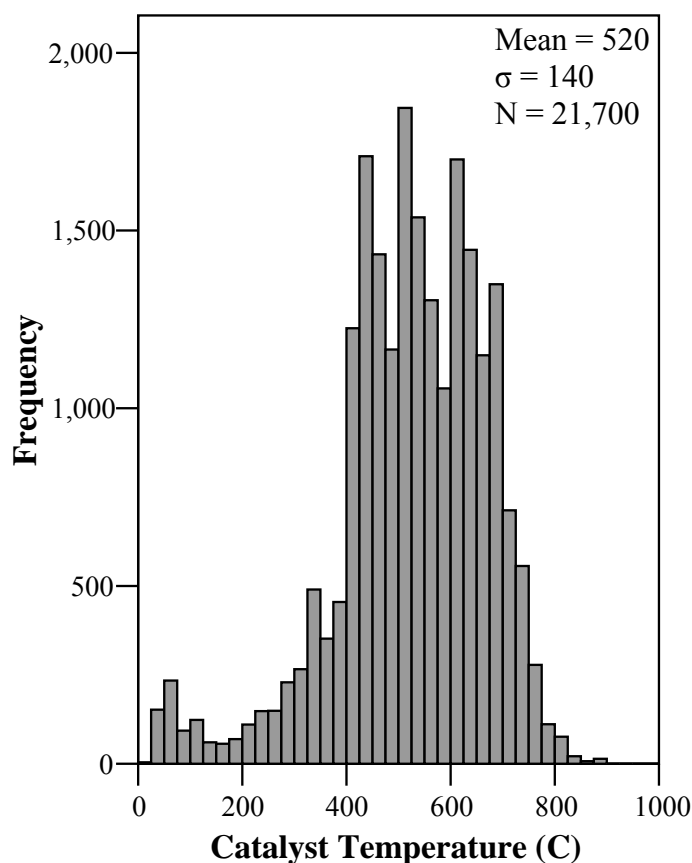


Figure 5.27. Histogram of catalyst temperatures (in-use catalyst, Unified Cycle, and UDDS cycle).

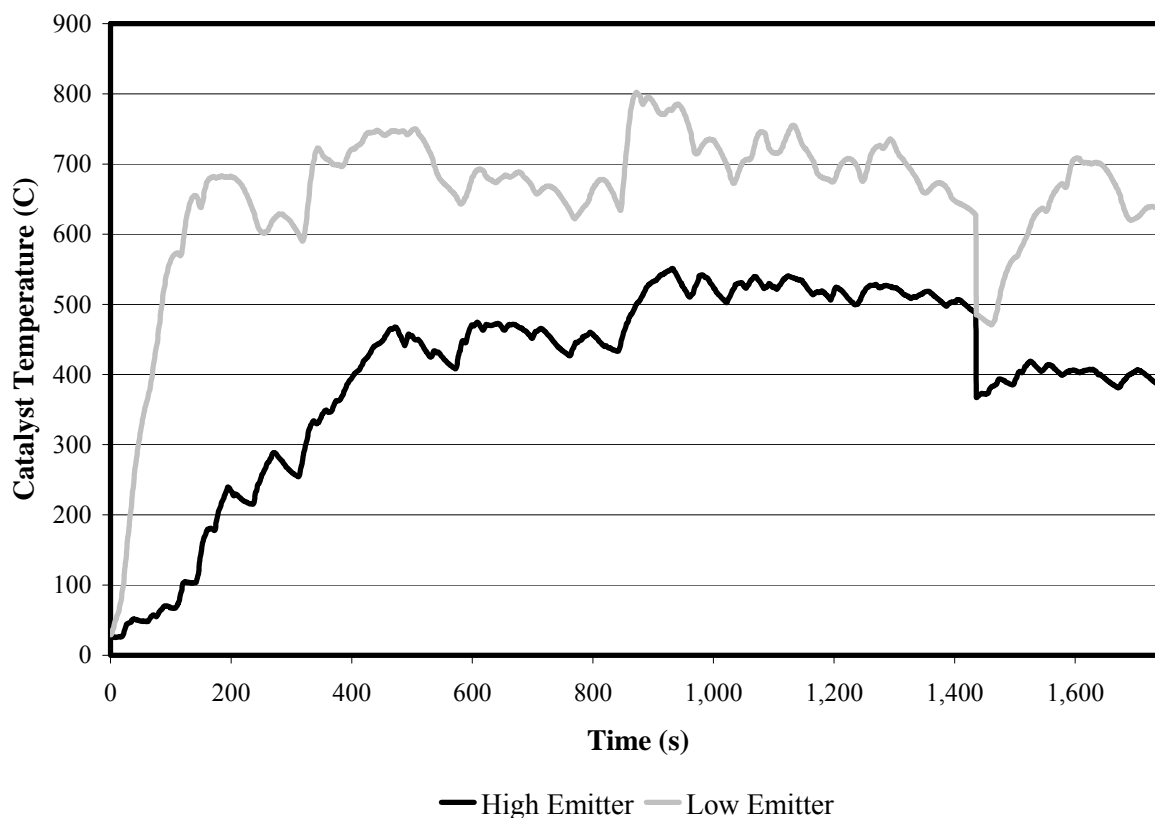


Figure 5.28. Typical real-time catalyst temperatures for high and low emitting vehicles.

Segment five was similar to segment three, where catalyst temperatures reached their highest values and no extreme acceleration events were present. Segments six comprised the beginning of the hot-start phase, where catalyst temperatures dropped due to the 10-minute soak period. This segment was similar to segment two but shorter in duration since the catalyst was already warm and did not require as long to reach operating temperatures. Segment seven was similar to segments three and five, and lasted until the end of the driving cycle.

Figure 5.30 was divided into two sections based on the N₂O emission patterns for a low N₂O emitter vehicle and their relationship with catalyst temperatures. The first segment comprised the beginning of the cold-start cycle, where for about 150 seconds catalyst temperatures were within the range in which N₂O formation is enhanced (between 120 and 550 °C). Segment two comprised the remainder of the test cycle in which dilute exhaust N₂O concentrations were close to ambient air levels due to the efficient conversion of NO to N₂ at high catalyst temperatures. These results suggest that once catalyst temperatures have reached ~650 °C, production of N₂O is almost negligible.

Figure 5.31 shows a scatter plot between dilute exhaust N₂O concentrations and catalyst temperatures for all test vehicles equipped with in-use catalysts and tested under the UC and UDDS cycle. This figure was divided into four segments. Segment one represents those portions of the driving cycles in which the temperatures were too low (less than 120 °C) for the

reduction of nitric oxide to be significant. N₂O production in these segments was quite limited. Segment two represents those portions of the driving cycles in which N₂O production was maximized (between 120 and 550 °C). Segment three represents those portions of the driving cycles in which catalyst temperatures were between 550 and 650 °C. Under these conditions, N₂O production started decreasing and most of the elevated N₂O observations were correlated with periods of extreme accelerations. Segment four represents the portions of the driving cycles in which catalyst temperatures were above 650 °C. As mentioned before, N₂O production is significantly restricted under these catalyst operating conditions.

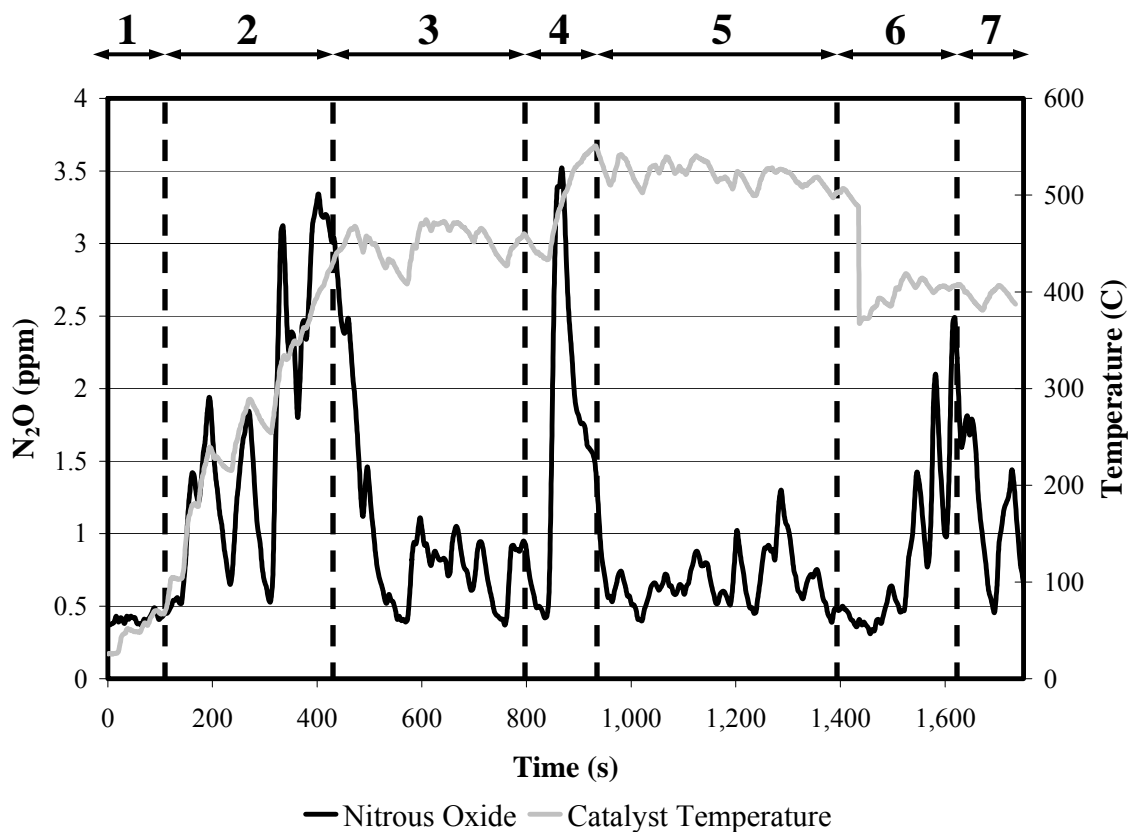


Figure 5.29. Catalyst temperature and nitrous oxide dilute exhaust concentrations for a high emitting vehicle (UC). See text for discussion of segments 1-7.

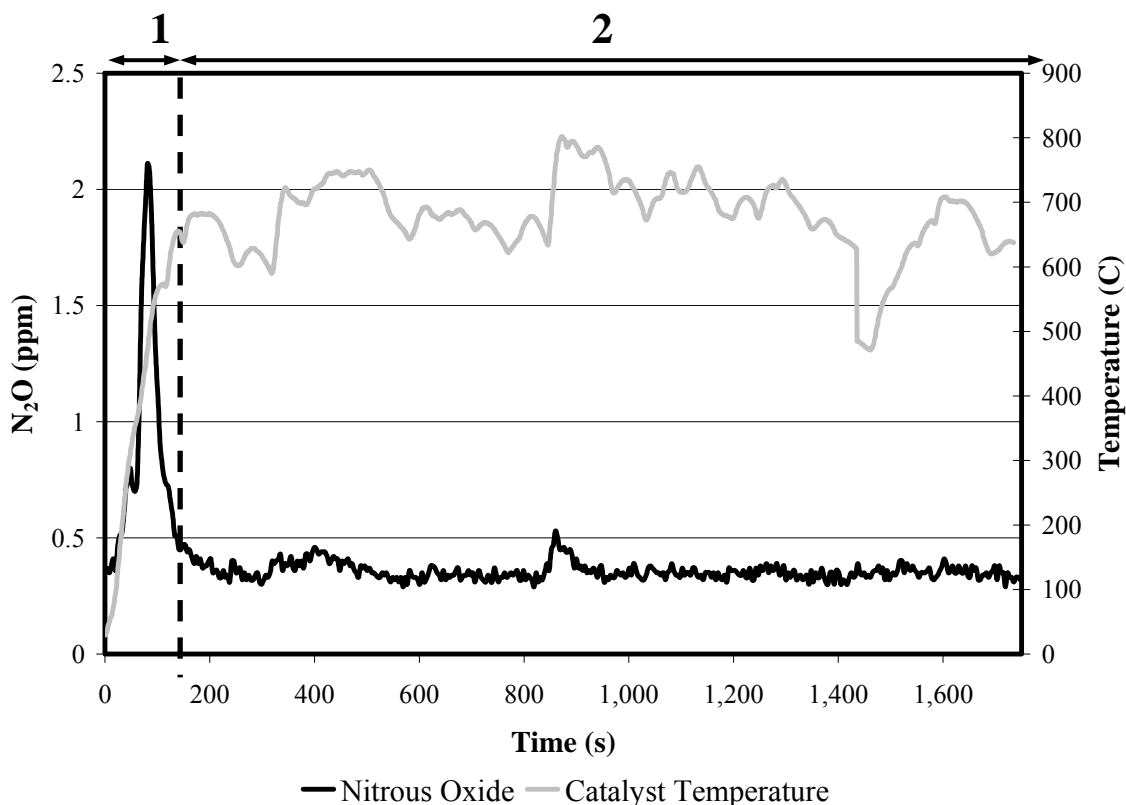


Figure 5.30. Catalyst temperature and nitrous oxide dilute exhaust concentrations for a low emitting vehicle (Unified Cycle). See text for discussion of segments 1 and 2.

5.3.5. Effect of Driving Cycle

As discussed in Section 4.5, driving cycle is among the factors that significantly affect vehicular emissions of nitrous oxide and other exhaust species. This effect, however, is small compared to other factors such as the overall performance of the catalytic converter.

Figure 5.32 shows the catalyst temperatures' cumulative frequency distributions for vehicles tested under the UC and UDDS cycle. As discussed above, catalyst temperatures for vehicles equipped with underperforming catalytic converters (high emitters) were much lower than those for vehicles equipped with catalytic converters operating normally (low emitters).

Figure 5.32 also shows that among high emitters, Unified Cycle tests yielded higher catalyst temperatures. The same was true among low emitters. However, the overall impact of driving cycle on catalyst temperatures was about 4 times smaller than the overall impact of catalyst performance (high emitter vs. low emitter) on catalyst temperatures. Figure 5.33 presents additional evidence to document the effect of driving cycle on catalyst temperatures when testing a high emitter vehicle (see below).

Figure 5.34 depicts typical real-time series for N₂O concentrations by driving cycle for a high N₂O emitter. During the cold-start phase (segment 1 in figures 5.33 and 5.34), while catalyst temperatures were comparable between the two driving cycles and within the optimal

interval for nitrous oxide production (see figures 5.31 and 5.33), N₂O dilute exhaust concentrations were first higher for the UDDS cycle and then higher for the Unified Cycle, consistent with the acceleration patterns for these cycles during the cold-start phase (see Figure 3.12).

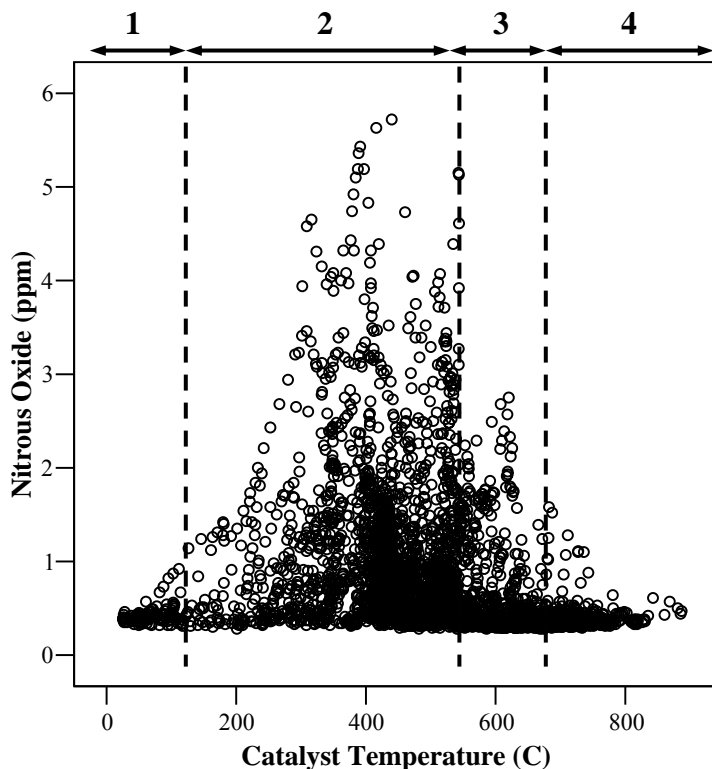


Figure 5.31. Scatter plot between dilute exhaust nitrous oxide concentrations and catalyst temperature measurements during the UC and UDDS cycle. See text for discussion of segments 1-4.

During the hot-stabilized phase (segment 2 in figures 5.33 and 5.34), apart from a large N₂O concentration spike (peak A in Figure 5.34) observed for the Unified Cycle (caused by the strongest acceleration of the entire cycle), the UDDS cycle exhibited higher dilute exhaust nitrous oxide concentrations. During this part of the cycles, where catalyst temperatures reached their highest values, the stronger acceleration patterns of the Unified Cycle compared to the UDDS cycle (see Figure 3.12) produced higher catalyst temperatures and resulted in lower N₂O emissions. However, if these acceleration patterns were too strong, like the period depicted by peak A in Figure 5.34, the N₂O-minimizing effect of the increase in catalyst temperatures was overwhelmed by the N₂O-enhancing effect of the acceleration when testing high emitting vehicles. This issue is further discussed in Section 5.3.6.

As shown in Figure 5.33, at the beginning of the hot-start phase for both cycles, catalyst temperatures were already within the optimal range for N₂O production (the 10-minute soak period is not long enough for the catalyst to cool down to room temperature). This figure also shows that due to the less aggressive acceleration patterns of the UDDS cycle, the highest catalyst temperatures during the third phase of this cycle were reached after longer periods of

time compared to the Unified Cycle (sections A and B in Figure 5.33). The combined effect of these two factors resulted in higher emissions for the UDDS cycle compared to the Unified Cycle (peak B in Figure 5.34). This also resulted in higher emissions during the third phase compared to the first phase for the UDDS cycle.

Figure 5.35 shows typical real-time series for dilute exhaust N₂O concentrations by driving cycle for a low emitter vehicle. For this type of vehicle and due to the appropriate performance of their catalyst, high temperatures were quickly reached after the beginning of the cold-start phase and even more rapidly after the beginning of the hot-start phase for both driving cycles (see Figure 5.36), resulting in a brief period of significant N₂O production during the first 150 seconds of the cycles. As shown in Figures 5.32 and 5.36, catalyst temperatures for these vehicles were elevated during most of the remainder of the cycles and stayed close to 650 °C, resulting in almost no nitrous oxide emissions. It is also important to note that at such high catalyst temperatures, the effect of the acceleration patterns was less noticeable. When testing low emitting vehicles, we did not observe significant N₂O concentration spikes during the hot-stabilized mode such as the concentration spike present when testing high emitters (see peak A in Figure 5.34).

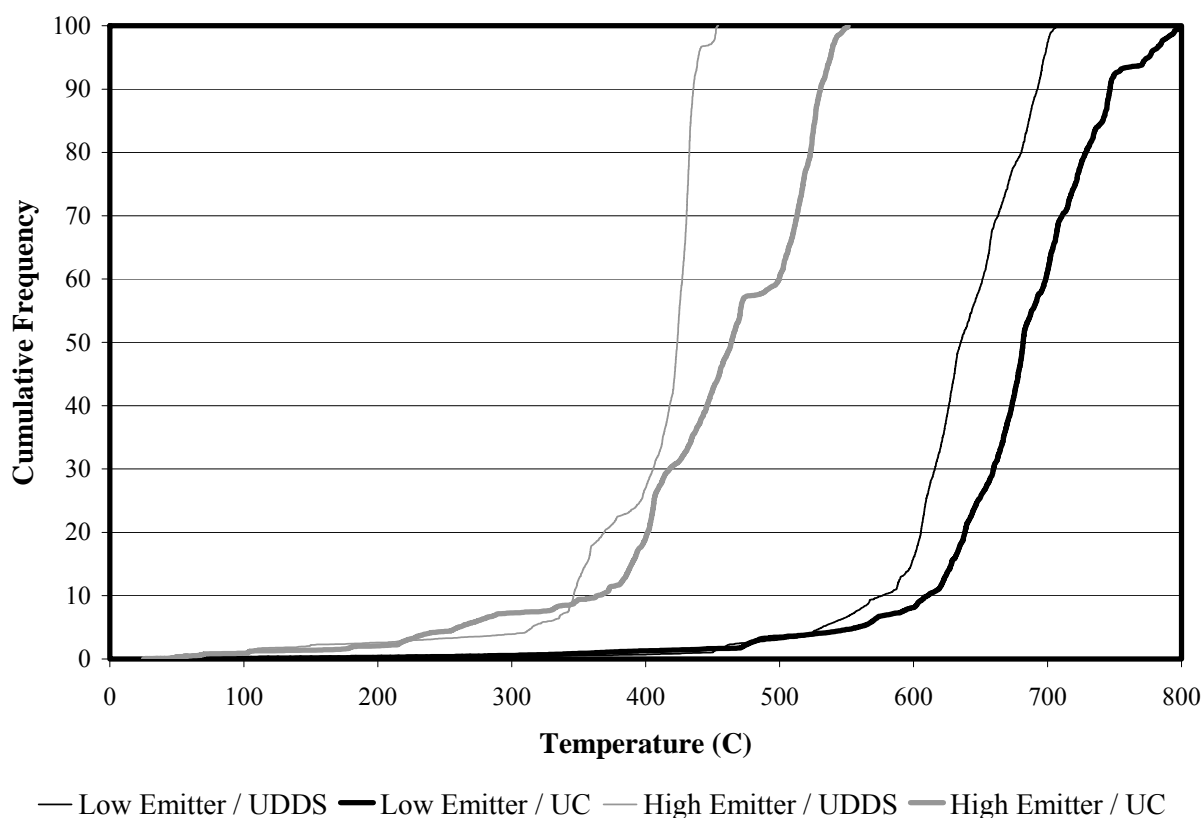


Figure 5.32. Catalyst temperatures' cumulative frequency distributions for vehicles tested under the UC and UDDS cycle.

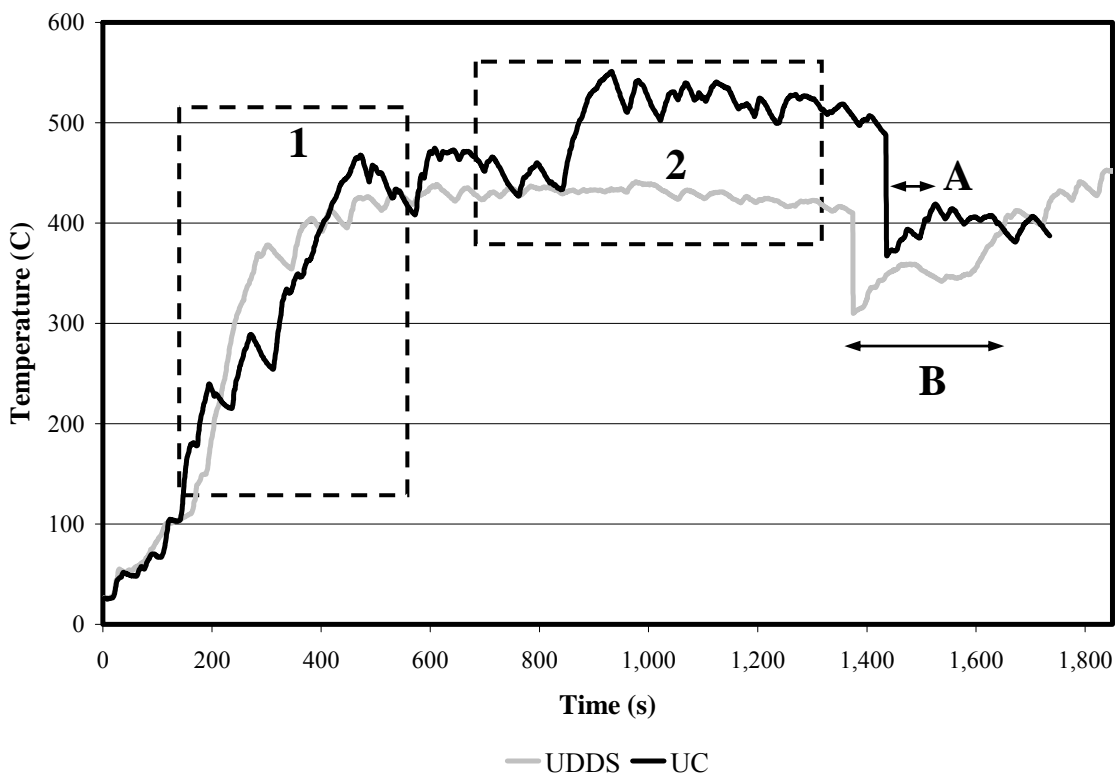


Figure 5.33. Typical real-time series for catalyst temperatures by driving cycle (high N₂O emitter).

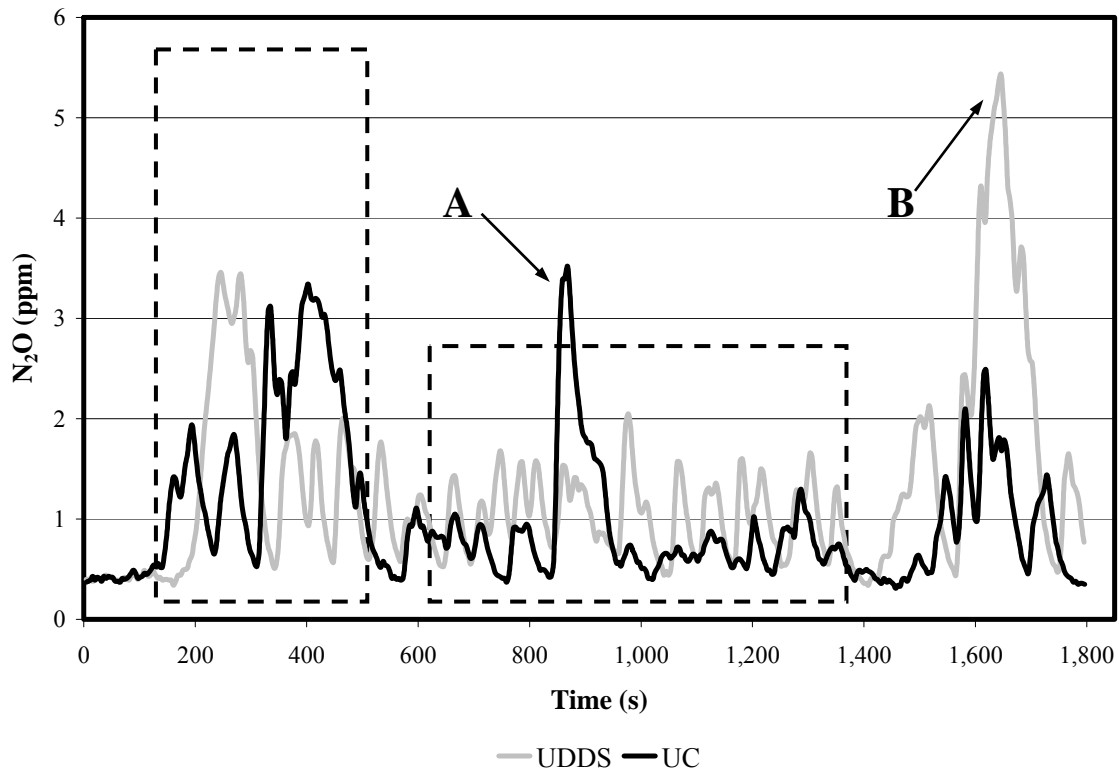


Figure 5.34. Typical real-time series for N₂O concentrations by driving cycle (high N₂O emitter).

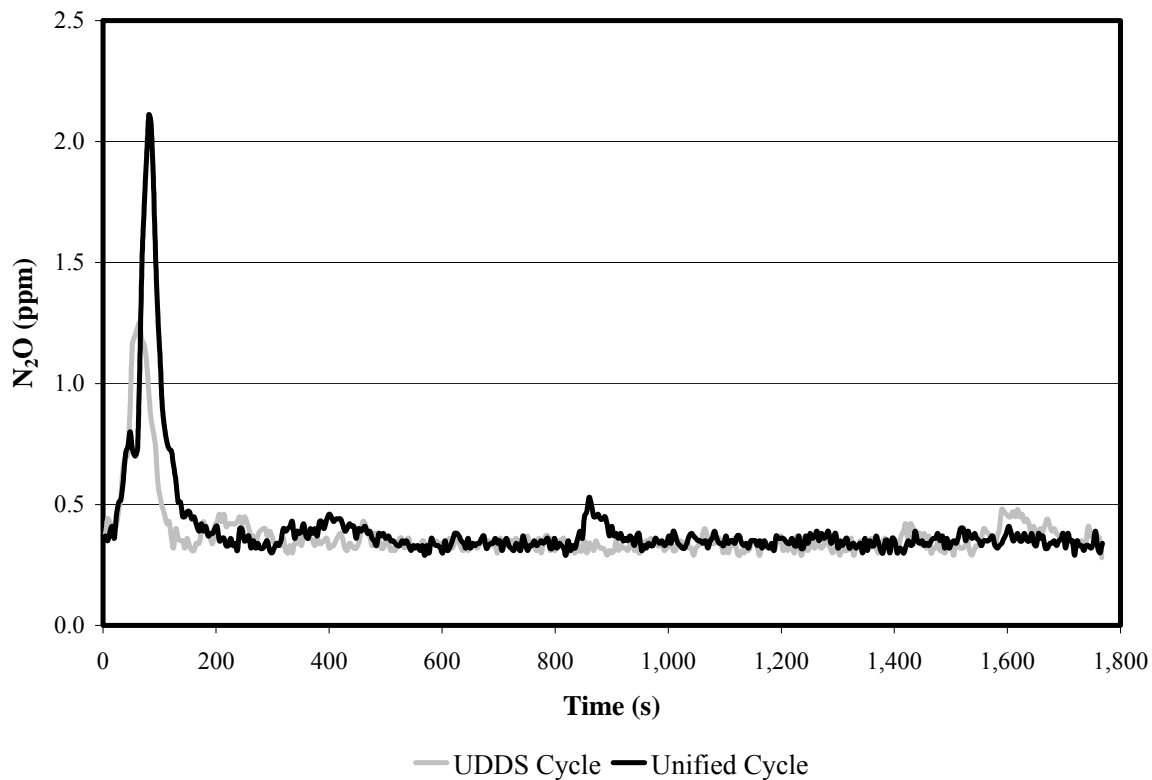


Figure 5.35. Real-time series for N₂O concentrations by driving cycle (low N₂O emitter).

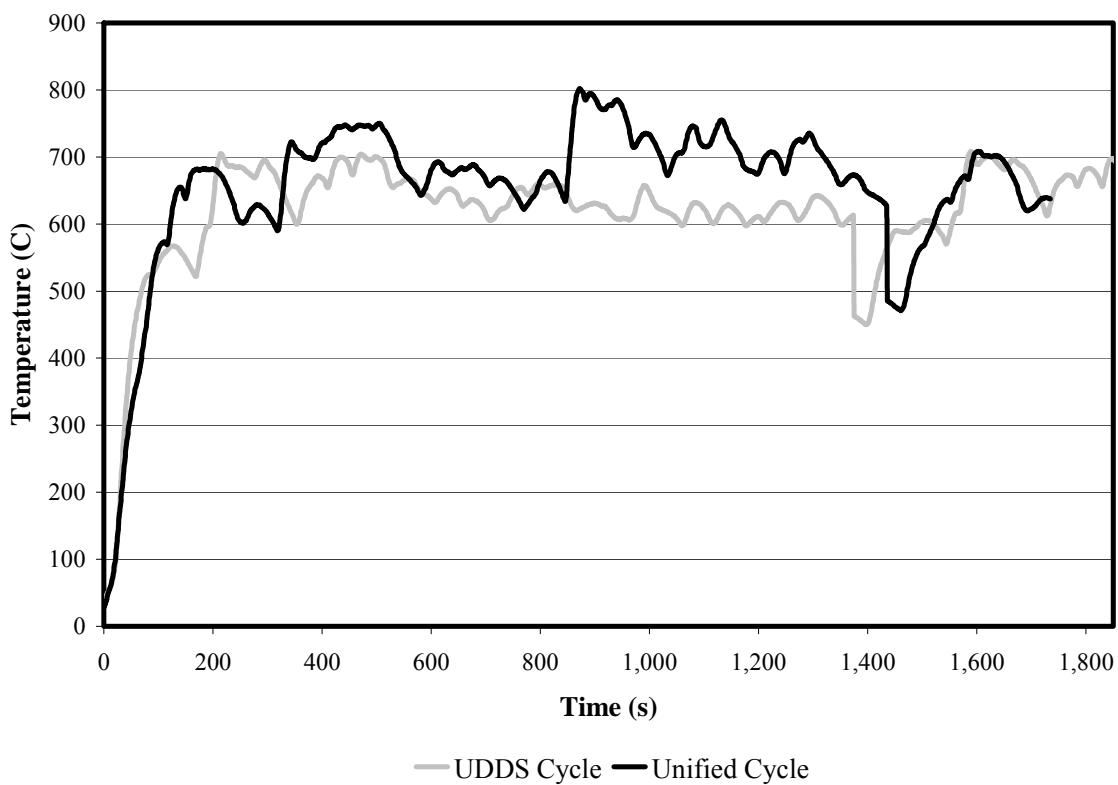


Figure 5.36. Real-time series for catalyst temperatures by driving cycle (low N₂O emitter).

5.3.6. Combined Effect of Accelerations and Catalyst Temperature

As discussed in the previous section, given the presence of catalytic species (precious metals) and the appropriate support medium (catalyst substrate), catalyst temperatures determine the formation of nitrous oxide inside the catalytic converter. In general, small quantities of N₂O are produced if catalyst temperatures are below 120 °C or above 650 °C. N₂O production is maximum between 120 and 550 °C and is less important between 550 and 650 °C.

If catalyst temperatures are below 650 °C, driving patterns may also play a significant role in two different ways: 1) aggressive and frequent accelerations increase catalyst temperatures and hence reduce N₂O emissions, 2) single steep accelerations produce brief periods in which N₂O production increases.

To better understand the effect of these two variables (catalyst temperature and driving patterns) we designed a custom driving cycle (MN₂O cycle – see Figure 15) to isolate and quantify their effect on the emissions of nitrous oxide from light-duty vehicles. As described in Section 3.3.6, the cold-start and hot-start phases of this cycle began with the engine idling for 180 seconds followed by four accelerations and four steady-state segments. The first two accelerations were fast accelerations (6.5 km h⁻¹ s⁻¹) and the other two accelerations were slow accelerations (1.5 km h⁻¹ s⁻¹).

5.3.6.1. High N₂O emitters

Figure 5.37 depicts typical nitrous oxide and catalyst temperatures during an MN₂O cycle conducted on a high emitter vehicle. For these types of vehicles, catalyst temperatures did not increase significantly during the idling period (point A). As expected, no N₂O production was observed during idling since in addition to low catalyst temperatures, the lack of load to the engine resulted in no production of nitrogen oxides.

Once the vehicle was subject to the two fast accelerations, catalyst temperatures and dilute exhaust nitrous oxide concentrations increased rapidly (points B). The first of the two slow accelerations caused N₂O emissions smaller than those produced under the fast acceleration (point C). The second slow acceleration produced even lower N₂O emissions since at that point of the driving cycle catalyst temperatures were already above 550 °C (point D).

During the hot-stabilized mode, catalyst temperatures were close to 550 °C, therefore N₂O emissions were lower than during the cold-start phase and subject to the change in accelerations (section E).

During the beginning of the hot-start phase, catalyst temperatures stayed constant around 420 °C and the lack of accelerations in the 180-second idling period caused a slight drop in N₂O production (point F). The first fast acceleration of the hot-start phase generated high concentrations of nitrous oxide (point G), although lower than those produced during the first fast acceleration of the cold-start phase since catalyst temperatures during this period ranged between 420 and 480 °C, in contrast to the range between 90 and 400 °C during the cold-start phase. By the time the second fast acceleration of the hot-start phase was applied, catalyst temperatures were already above 550 °C, resulting in lower N₂O emissions compared to the first fast acceleration of this phase (point H). The first slow acceleration of the hot-start phase (point

I) produced similar N₂O emissions to the second fast acceleration of the same phase (point H) since catalyst temperatures were close to 600 °C and the effect of driving patterns was less important.

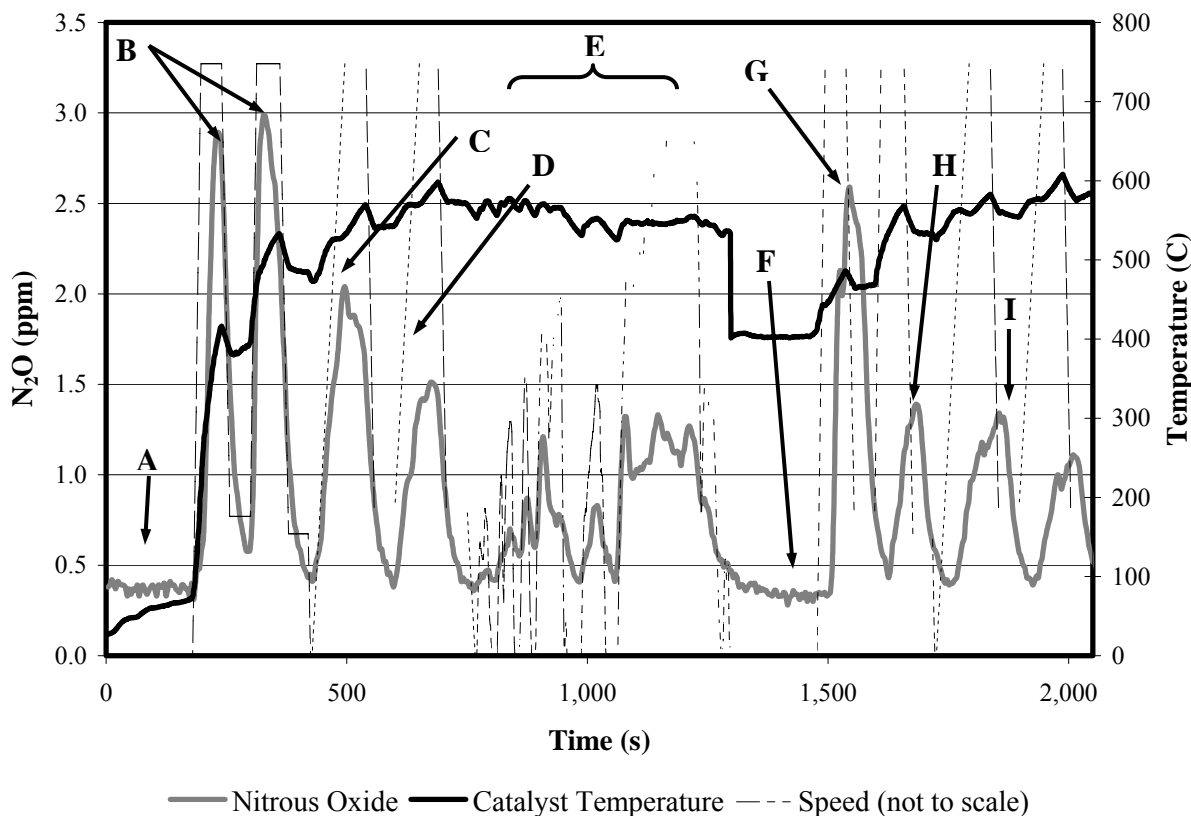


Figure 5.37. Nitrous oxide and catalyst temperatures during a MN₂O cycle (high emitter).

5.3.6.2. Low N₂O Emitters

Figure 5.38 depicts typical nitrous oxide and catalyst temperatures during an MN₂O cycle conducted on a low emitter vehicle. In this case, in contrast to high emitters, catalyst temperatures increased without any load being applied to the vehicle (point A). Around 50 seconds after the engine was turned on, the vehicle was put in gear, generating a small pulse of NO that was rapidly converted to N₂O since catalyst temperatures were within the optimal range for its production (point B).

By the time the first fast acceleration of the cold-start phase was completed, catalyst temperatures were already above 650 °C and stayed at these levels for the majority of the cycle. This resulted in dilute exhaust nitrous oxide concentrations close to ambient levels regardless the acceleration patterns, confirming the findings discussed in previous sections of this report.

Finally, catalyst temperatures for low emitting vehicles tracked more closely the driving cycle speed (see Figure 5.38), compared to catalyst temperatures for high emitting vehicles (Figure 5.37). This phenomenon, however, due to the high temperatures observed for low emitters, appeared to have no significant effect on nitrous oxide emissions from the tested fleet.

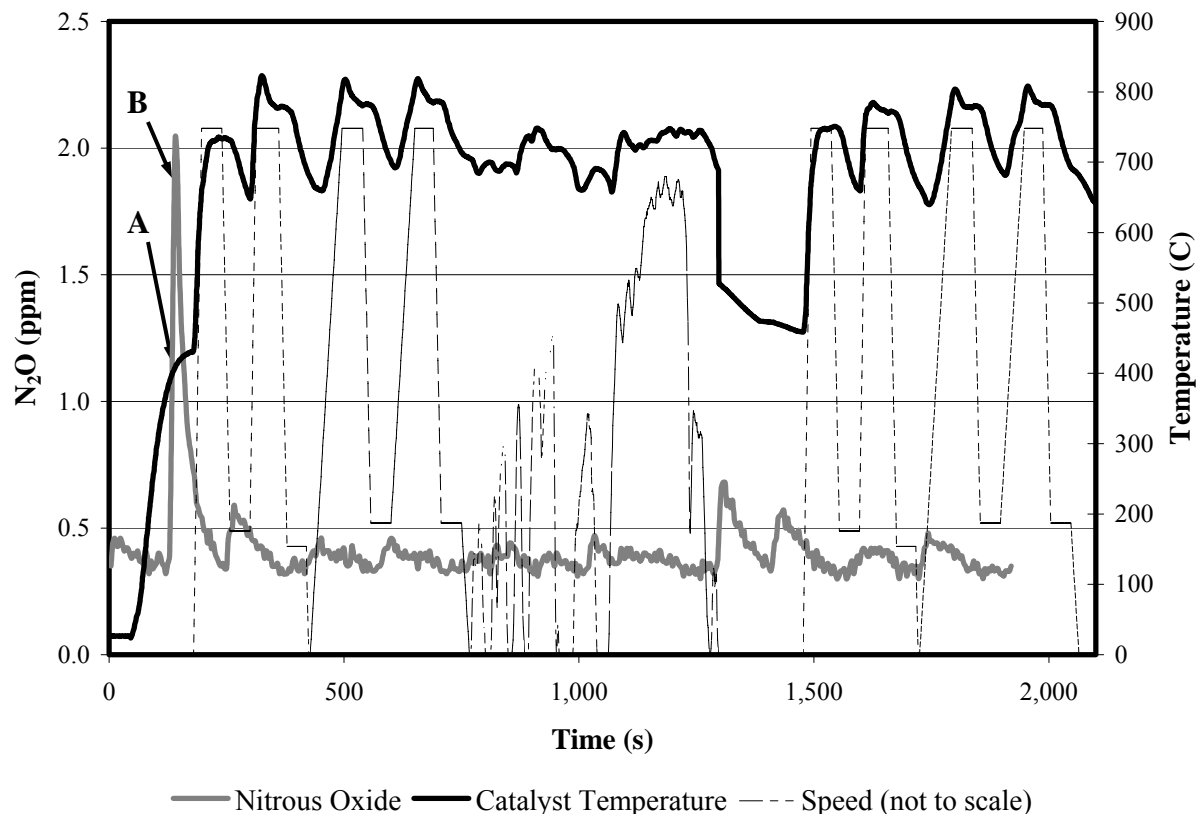


Figure 5.38. Nitrous oxide and catalyst temperatures during a MN₂O cycle (low emitter).

5.3.7. Effect of Catalyst

As discussed elsewhere, nitrous oxide is formed as an intermediate in the catalytic reduction of nitrogen oxides. Thus, no significant N₂O emissions are expected for vehicles without three-way catalysts. We have also discussed N₂O emissions are a function of catalyst performance (i.e. catalyst temperatures) and that vehicles equipped with aged or faulty catalysts produce higher emissions of N₂O than vehicles equipped with newer and/or well performing catalytic converters.

Figure 5.39 depicts the three alternatives above. These data, obtained from a light-duty truck initially categorized as a high N₂O emitter and tested under the Unified Cycle, show the substantial differences, in terms of N₂O emissions, between vehicles tested using different catalyst configurations. The in-use catalyst results for this high emitter show the N₂O concentration patterns discussed in Section 5.3.6.1. When the same vehicle was tested again with an empty catalyst (after removing the catalyst substrate), no significant emissions of nitrous oxide were observed throughout the entire driving cycle. Finally, when the same vehicle was tested after installing a new OEM catalyst, it exhibited the characteristics of a low N₂O emitter (see Section 5.3.6.2).

Figure 5.40 shows nitric oxide dilute exhaust concentrations for the same experiments depicted in Figure 5.39. In-use catalyst (for this high emitter vehicle) and empty catalyst (i.e., engine-out emissions) configurations exhibited comparable patterns of NO concentrations,

providing further evidence that high N₂O emissions are caused by underperforming catalytic converters. Nitric oxide emissions for the new-catalyst configuration were much smaller than for the other two configurations.

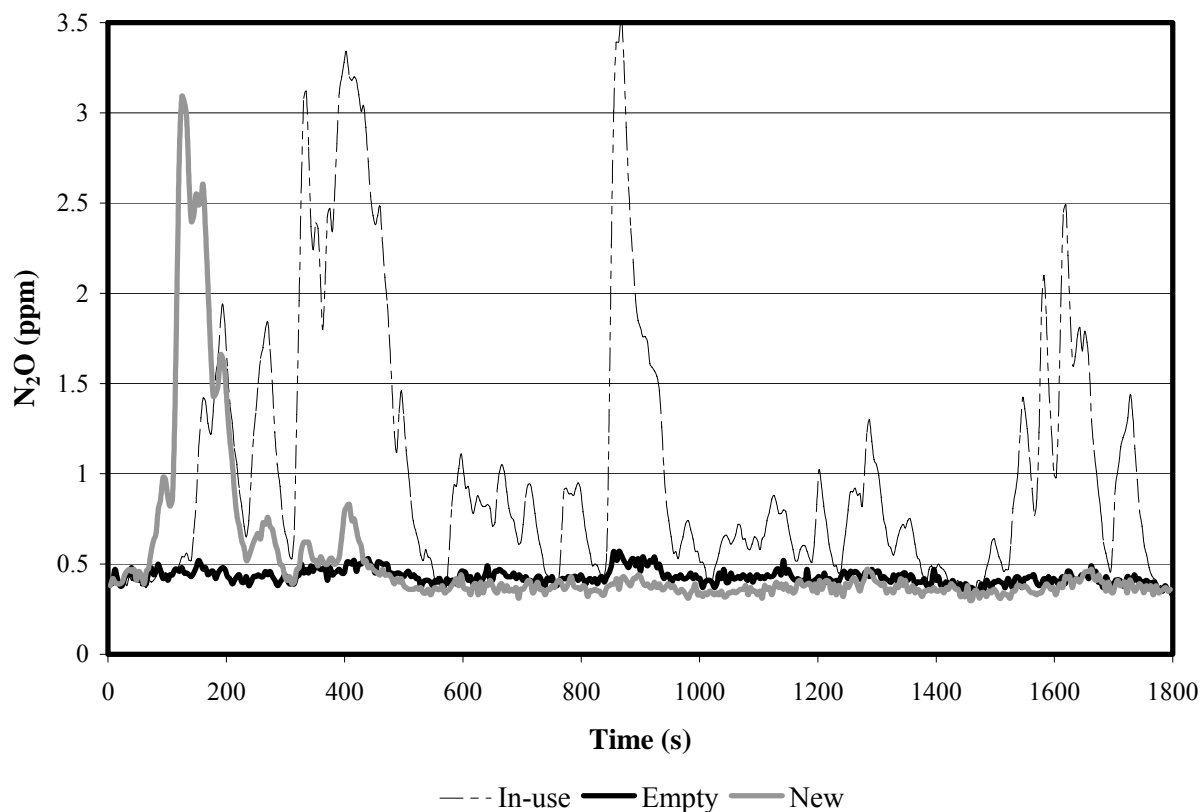


Figure 5.39. Real-time series for dilute exhaust nitrous oxide concentrations by catalyst configuration (high emitter) – Unified Cycle.

The empty catalyst experiments provided a unique dataset in which engine-out emissions were obtained under the same conditions and for the same vehicles for which in-use and new-catalyst emission data were obtained. For example, after comparing NO emissions obtained from in-use catalyst experiments with NO emissions obtained from empty catalyst experiments, we obtained an accurate estimate of the amount of nitric oxide reduced by the in-use catalyst. This quantity was compared with the amount of N₂O produced by the in-use catalyst to estimate the N₂O/NO ratios. Similar calculations are discussed in sections 4.8 and 6.3, however, those ratios refer only to tailpipe emissions and therefore are more limited in scope.

Ratios of N₂O tailpipe concentrations to the difference between engine and tailpipe NO concentrations varied between 0.01 and 0.14. As expected, low emitting/new catalyst vehicles exhibited the lowest ratios whereas high emitting/underperforming catalyst vehicles exhibited the highest ratios (more molecules of N₂O being produced by each molecule of NO being reduced).

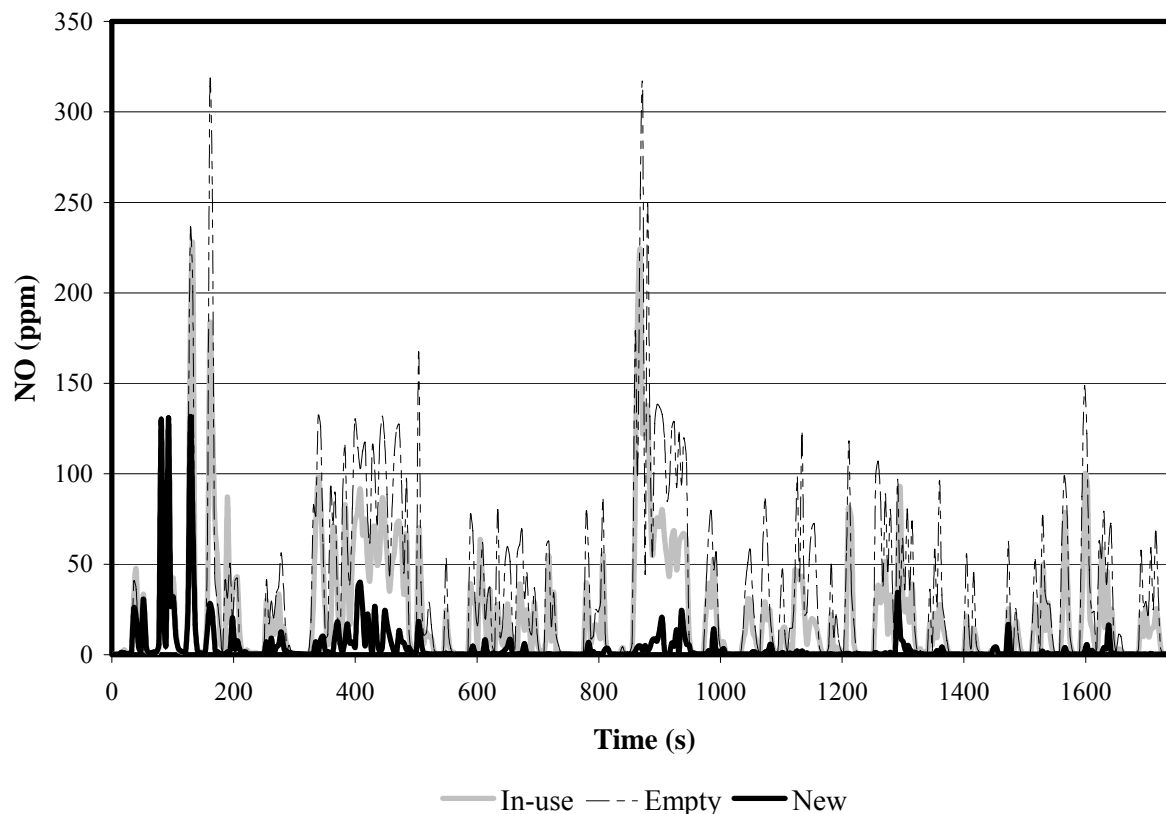


Figure 5.40. Real-time series for dilute exhaust nitric oxide concentrations by catalyst configuration (high emitter) – Unified Cycle.

5.4. Major Findings of Real-Time Analyses

Given the complexity of the information presented in this chapter, including discussion of variables that behaved in a non-linear fashion, we present a brief summary of the most important findings obtained from our real-time analyses. The implications of these results have been discussed above and will be expanded in the Conclusions section (see Chapter 7).

- A high correlation was observed between N₂O dilute exhaust concentrations determined by the two sampling methods (real-time and integrated samples) used during this study.
- Real-time A/F ratio data were comparable in all experiments for which such data were collected, suggesting the oxygen sensors of the test vehicles were performing as expected.
- The behavior of exhaust species, nitrous oxide in particular, varied considerably between experiments. Driving cycle, type of vehicle, and especially catalyst performance were among the factors accounting for such variation.

- Nitric oxide is the exhaust species for which we observed the highest correlation with nitrous oxide. This correlation varied significantly between experiments and was a function of catalyst performance.
- Exhaust temperatures are not an appropriate proxy for catalyst temperatures early in a cold-start cycle due to the heat capacity of the material of which the mixing tee, the tailpipe tip, and the junctions between the tailpipe and the mixing tee are built.
- The differences in timing and magnitude for N₂O real-time concentration spikes between the vehicle categories we studied were related to the time required for the catalysts to reach their operational temperatures. Catalyst warm-up periods for high emitting vehicles were longer than for low emitting vehicles.
- Catalyst temperatures below 120 °C are not adequate for NO reduction. Hence, N₂O production is very limited for temperatures under 120 °C. N₂O catalytic formation is enhanced between 120 and 550 °C. Catalyst temperatures above 650 °C generate optimal conditions for the reduction of NO to N₂, resulting in negligible production of N₂O.
- High N₂O emitting vehicles were also high emitters of NO, CO and CH₄, confirming these vehicles were equipped with ineffective catalytic converters.
- Catalyst temperature is a good proxy for catalyst performance and exhaust emissions for TWC vehicles. Better catalyst performance is associated with higher catalyst temperatures and results in lower emissions. However, catalyst temperature measurements are difficult and expensive, and thus not feasible for in-use testing programs.
- Driving conditions (driving cycle) significantly affect catalyst temperatures. Higher catalyst temperatures are associated with aggressive accelerations. Therefore, catalyst temperatures are a function of both acceleration patterns and catalyst type and performance.
- However, the effect of driving conditions is less noticeable when the catalyst is operating at very high temperatures. Therefore, for well performing catalysts (i.e., able to rapidly reach high temperatures), driving cycle has a second-order effect on N₂O emissions.
- No significant emissions of nitrous oxide were observed when testing vehicles equipped with empty catalysts
- To obtain realistic and meaningful N₂O/NO emission ratios, it is necessary to measure both engine-out and tailpipe emissions.

6. COMPREHENSIVE ANALYSIS OF INTEGRATED SAMPLES

In this chapter we summarize the results of the analyses conducted with the complete integrated samples dataset, including vehicles tested during both the pilot and main studies. As mentioned in Section 3.1, our integrated samples database was comprised of 264 experiments conducted on 134 vehicles (see Table 6.1).

Table 6.1. Summary of test vehicles used during main study

Parameter	Vehicle characteristic	Number of vehicles tested
Certification standard	TIER0 ¹	41
Certification standard	TIER1 ¹	30
Certification standard	TLEV	20
Certification standard	LEV	39
Certification standard	ULEV	4
Vehicle class	LDT	48
Vehicle class	PC	86
Odometer	0 - 20,000	5
Odometer	20,000 - 40,000	14
Odometer	40,000 - 60,000	18
Odometer	60,000 - 80,000	22
Odometer	80,000 - 100,000	24
Odometer	100,000 - 120,000	12
Odometer	120,000 - 150,000	15
Odometer	150,000 - 200,000	15
Odometer	> 200,000	9
Catalyst Type	TWC	125
Catalyst Type	Oxidation	9

¹ Non-LEV vehicles. These terms refer to federal emission standards (see Section 2.6).

6.1. Fuel Sulfur Content

During the course of the main study, gasoline samples were collected from the fuel tanks of 54 vehicles recruited for ARB's 17th VSP and analyzed for sulfur content using an ultraviolet fluorescence technique. In general, the fuel sulfur content was low and in compliance with California's regulations (annual average below 30 ppm never to exceed 80 ppm). As shown in Figure 6.1a, the variability between samples was low (mean = 14 ppm; $\sigma = 6.7$), with only one exception in which the fuel sulfur content was 55 ppm. The dynamometer tests conducted with this particular vehicle did not exhibit N₂O emissions significantly higher than the rest of the tested fleet (see Figure 6.1b). However, this does not mean sulfur content does not play a significant role in determining nitrous oxide emissions from gasoline-powered vehicles. In order to study this effect, which has been documented in previous research (Huai et al., 2004), it is necessary to have a wider range of fuel sulfur contents than was encountered in the present in-use vehicle study.

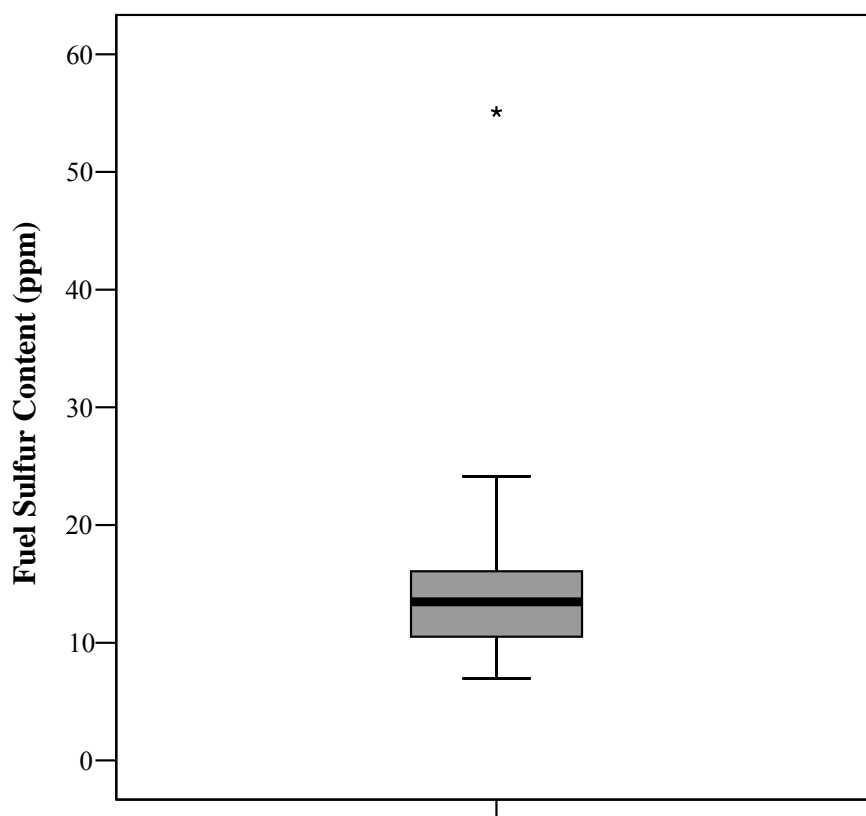


Figure 6.1a. Distribution of fuel sulfur content results.

(See Appendix C for box plot schematic and description)

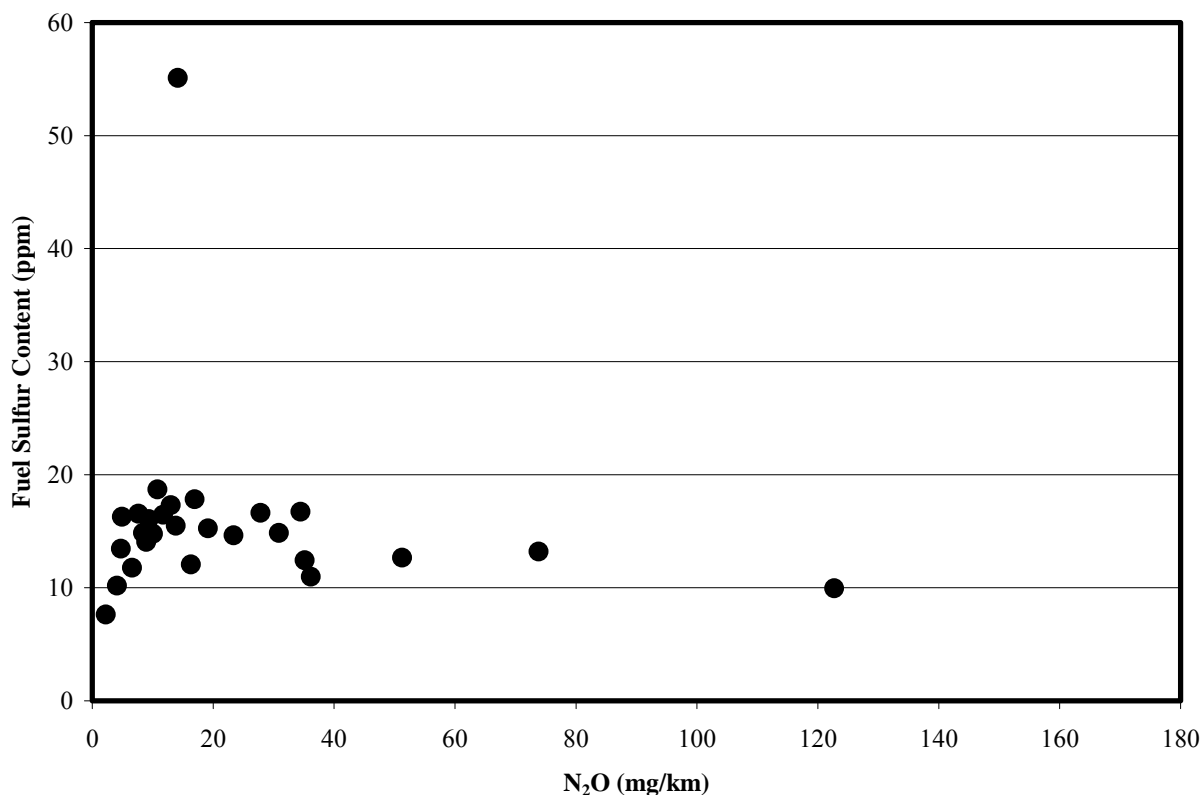


Figure 6.1b. Scatter plot between N₂O emission factors and fuel sulfur content.

6.2. Preliminary Analyses

Figure 6.2 depicts the nitrous oxide emission factors by driving cycle phase for all experiments for which integrated samples were collected. Consistent with the results presented in Section 4.6, N₂O emission factors for the hot-stabilized phase were significantly lower than for the other two phases. The median of the N₂O emission factors was highest for the cold-start phase. However, the single highest emission factors were observed during the hot-start phase, results that are also consistent with the discussion in Section 5.3.3.

Figures 6.3 and 6.4 present the distribution of the driving cycle-weighted (40 CFR § 86.144-90) N₂O emission factors for all vehicles tested in our study. The median emissions factor was 14 mg km⁻¹ and the mean emissions factor was 20 mg km⁻¹ (N = 264; σ = 22). There were eight extreme cases (emission factors above three times the interquartile range) in our sample. For the seven extreme cases exhibiting emission factors above 100 mg km⁻¹, five corresponded to large-engine displacement LDTs, six were for vehicles certified as TIER0 according to California emission standards, and six were for 1994 model-year or older vehicles. All extreme cases corresponded to vehicles with at least 190,000 kilometers on their odometers. Six of the seven experiments for which we found emission factors higher than 100 mg km⁻¹ were conducted using the less aggressive (i.e., lower temperatures) UDDS driving cycle.

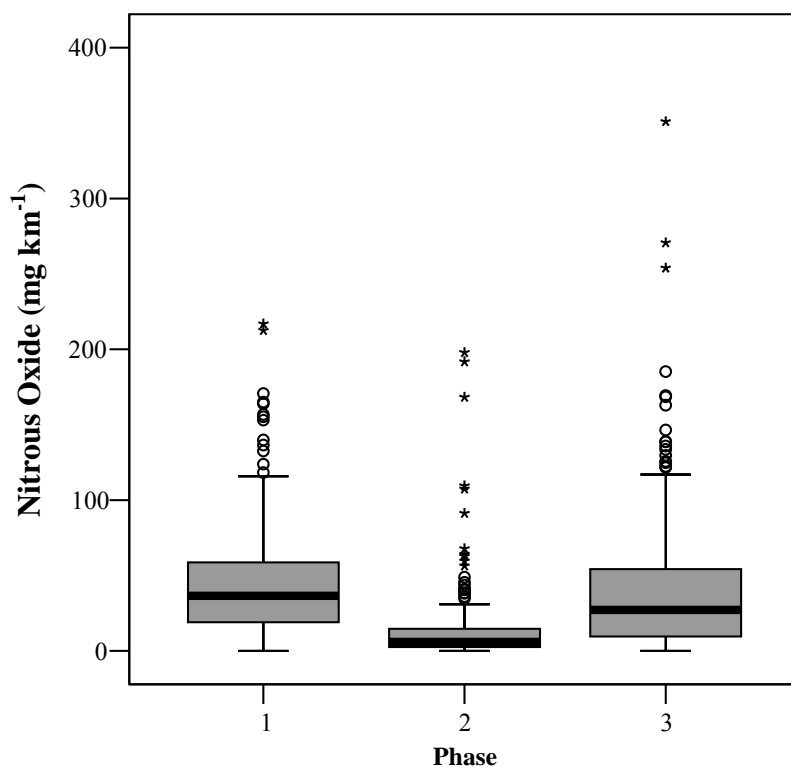


Figure 6.2. N₂O emissions by phase for all integrated sample experiments.

(See Appendix C for box plot schematic and description)

The four lowest weighted N₂O emission factors (less than 2 mg km⁻¹) were observed for 2001 LEV and ULEV passenger cars, tested under the Unified Cycle, and with less than 50,000 kilometers on their odometers.

The nitrous oxide emission factor data exhibited a left-tailed distribution with about 75% of the data points below 50 mg km⁻¹ (see Figure 6.4) and about 70% of all data points between one standard deviation from the mean (20 ± 22).

6.3. Analysis of Variables Affecting N₂O Emissions from Light-Duty Vehicles

As discussed in detail in Chapter 4, the interaction between the different variables affecting the catalytic production of N₂O creates a set of confounding factors that must be controlled before conducting further analyses. Figure 6.5 shows a schematic, similar to that presented in Figure 4.1, of the data filtering process used during the main study to isolate the effect of the confounding factors mentioned above. For example, to evaluate the effect of the vehicles' emission standards (TIER0, TIER1, etc.) on N₂O emissions, we did not use the entire 134-vehicle database (264 experiments) but a subset that included only passenger cars equipped with three-way catalysts and tested under the UDDS driving cycle. In other words, we determined the effect of emission standards on N₂O emissions while controlling for type of vehicle, type of catalyst, and driving cycle. The selection tree presented in Figure 6.5 was designed based on the results from our pilot study (Behrentz et al., 2004) and to optimize the sample size for our comparative analyses.

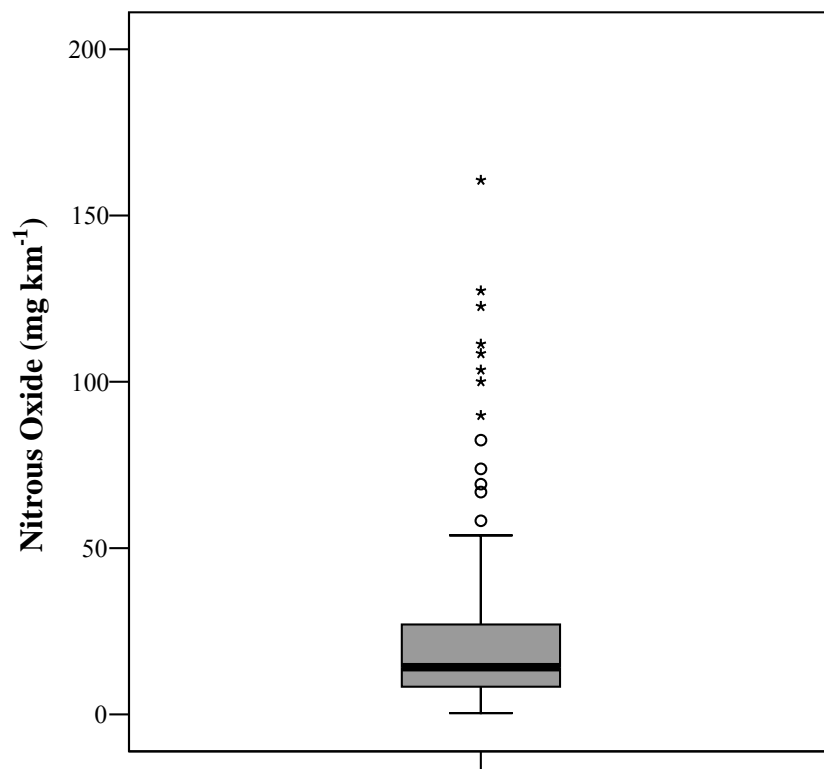


Figure 6.3. N₂O emission factors for the tested fleet.
(See Appendix C for box plot schematic and description)

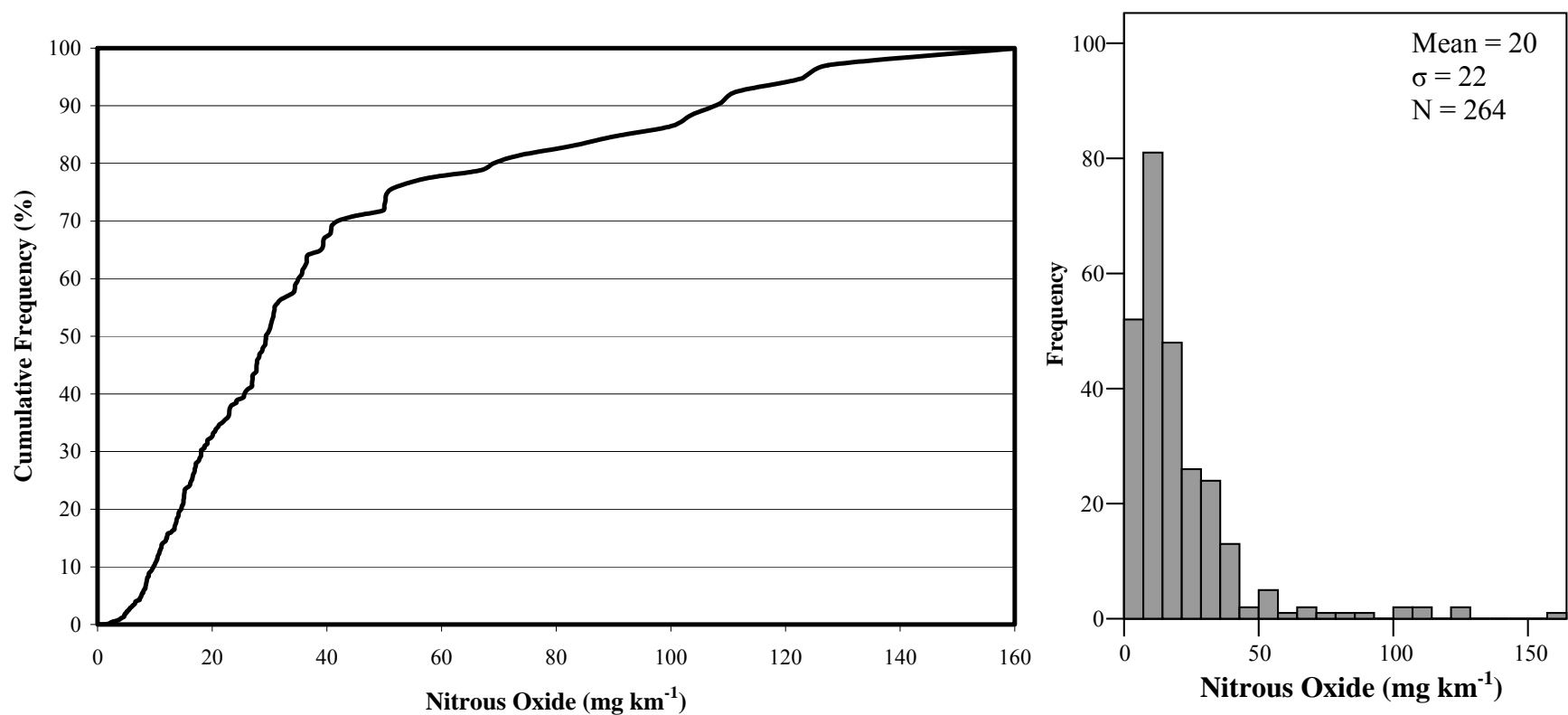


Figure 6.4. Nitrous oxide emission factor data distributions.

During the pilot study, the filtering process described above compromised the statistical robustness of our results due to the inherent reduction in sample size resulting from eliminating confounding variables. This issue was resolved for most analyses in the main study due to the much larger initial sample size of the complete integrated samples database.

6.3.1. Effect of Catalyst Type

As depicted in Figure 6.5, to evaluate the effect of catalyst type on N₂O emissions we used the following test vehicle configuration: PC/TIER0/UDDS. 38 vehicles met this configuration and were used to calculate the mean emissions during each of the three phases as well as the mean driving cycle-weighted emissions factor for the different catalyst types. Figure 6.6a summarizes these results.

Consistent with the findings of our pilot study, during the cold-start phase, vehicles equipped with three-way catalysts produced higher N₂O emissions compared with vehicles equipped with oxidation catalysts. These differences were less noticeable during the hot-start phase and not significant during the hot-stabilized phase.

Figure 6.6b shows the N₂O/NO_x tailpipe emissions ratios followed the same patterns of the weighted N₂O emission factors, where TWC vehicles exhibited higher ratios than vehicles equipped with oxidation catalysts.

However, these cannot be deemed as definitive results due to the small number of vehicles (2) equipped with oxidation catalyst for these analyses. We present additional data for oxidation catalyst vehicles in Section 6.4.

6.3.2. Effect of Driving Cycle

As shown in Figure 6.5, to evaluate the effect of driving cycle on N₂O emissions we used the following test vehicle configuration: PC/TWC/TIER0. Based on these characteristics 57 vehicles were selected, for which we calculated the mean emissions during each of the three phases as well as the mean weighted emission factors for the different driving cycles. Figure 6.7a summarizes these results and shows a significant difference between N₂O emissions for the two driving cycles. As expected and in agreement with the findings of our pilot study, the Unified Cycle yielded the highest emissions during the cold-start and hot-start phases.

However, as discussed in Section 5.3.5, due to the lower catalyst temperatures related to UDDS tests, the hot-stabilized phase emissions were higher for this cycle compared to those for the Unified Cycle. This, in conjunction with the longer duration of the Unified Cycle's hot-stabilized phase (compared to the UDDS cycle – see Section 3.3.6), resulted in higher weighted emission factors for the vehicles tested using the UDDS cycle.

Figure 6.7b shows the mean N₂O/NO_x emissions ratios, consistent with the weighted N₂O emissions, were higher for vehicles tested under the UDDS cycle than for vehicles tested under the Unified Cycle.

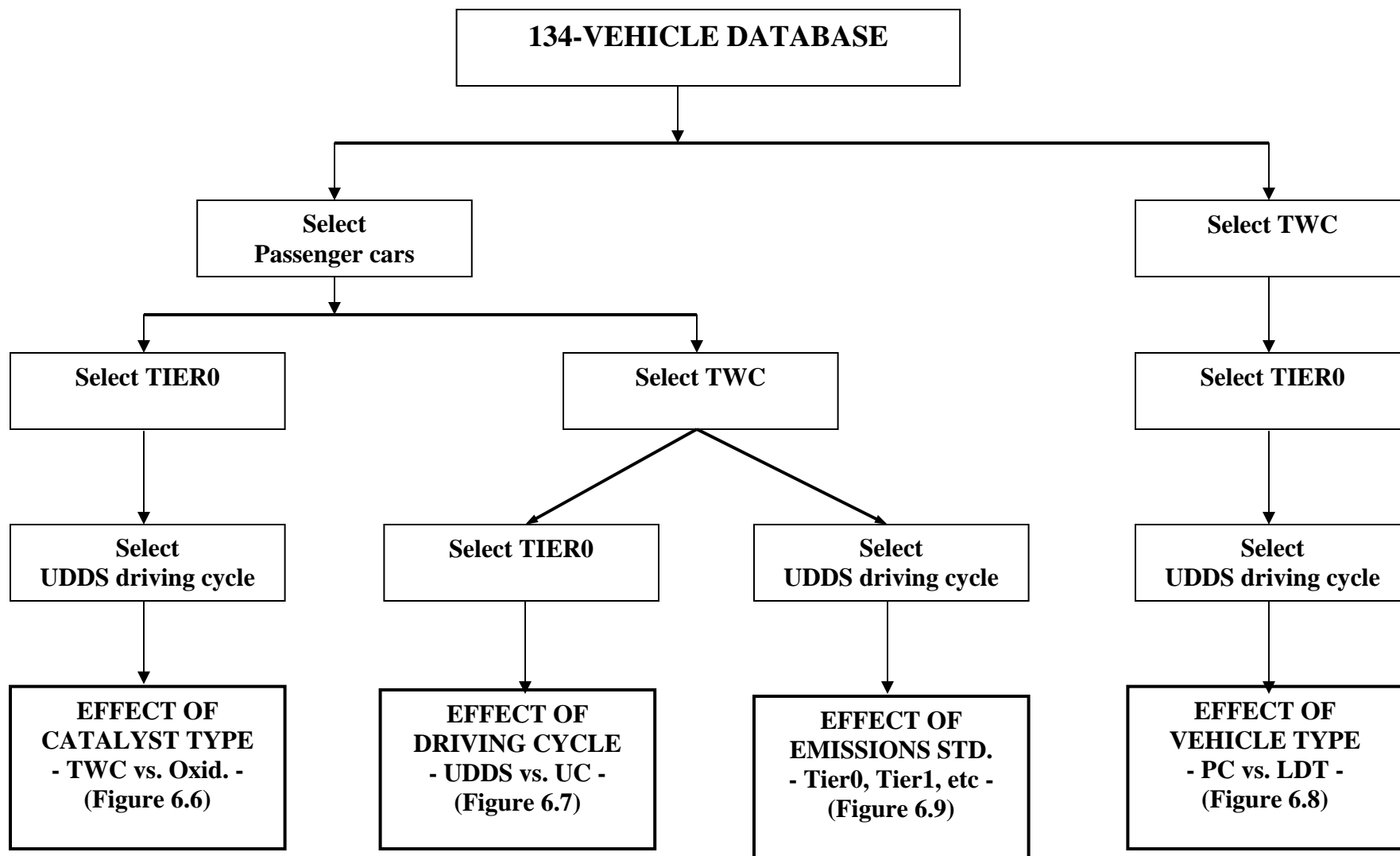
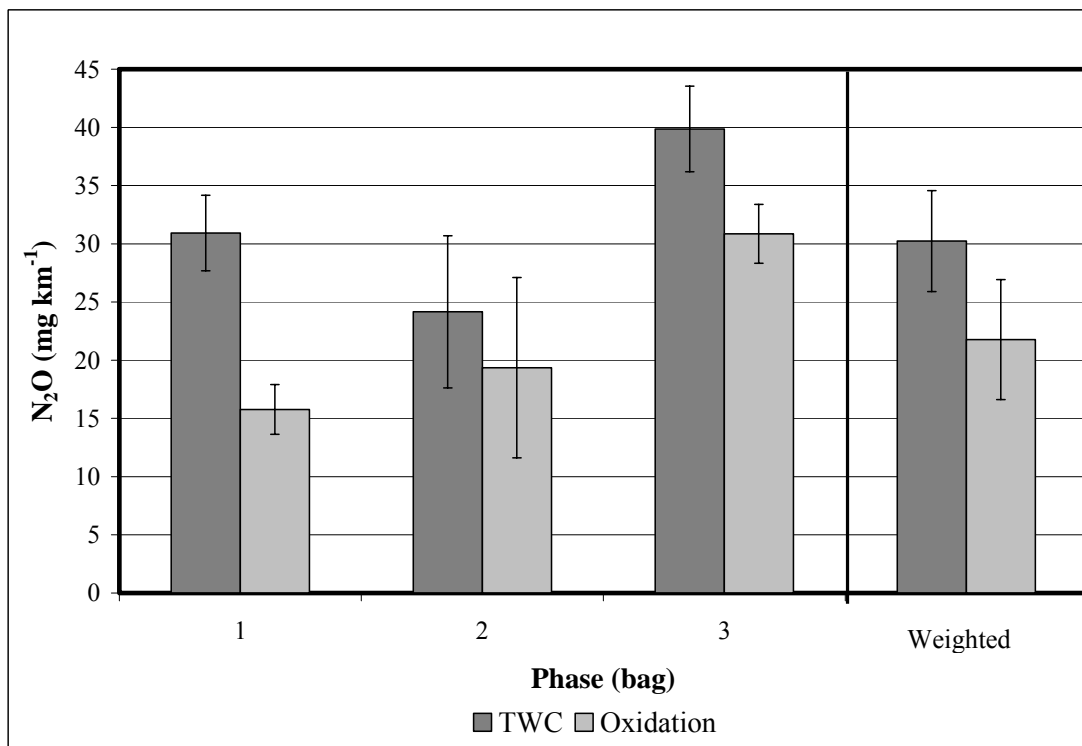
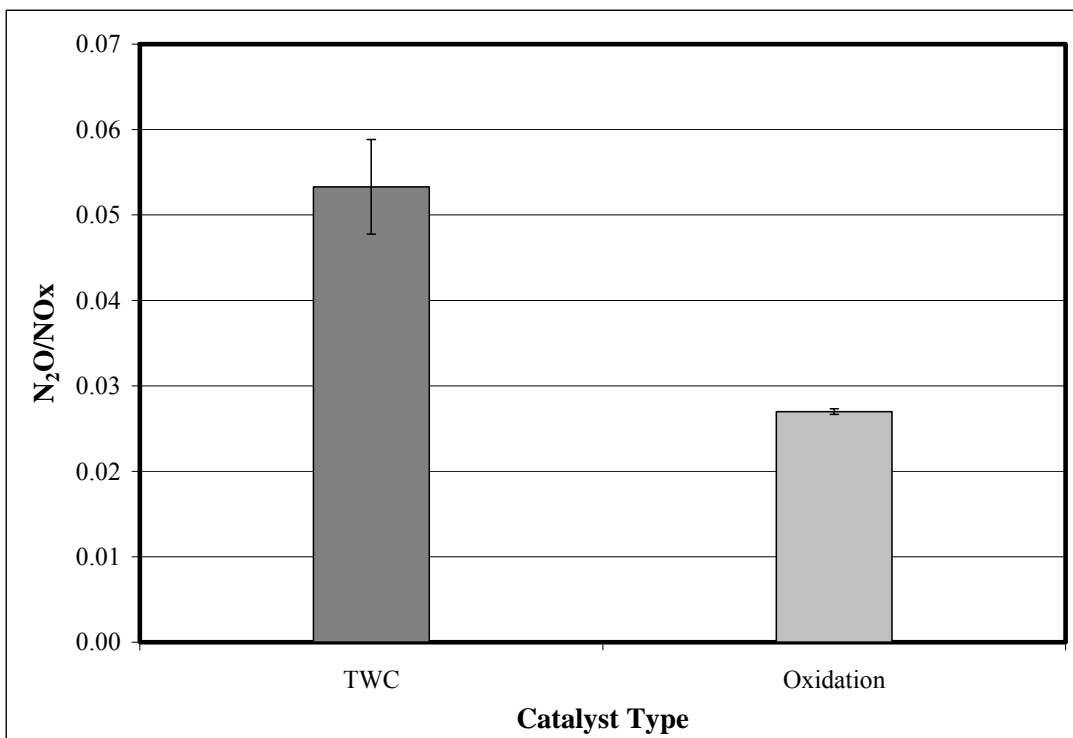


Figure 6.5. Schematic of the data selection and filtering required for comparative analyses (main study).

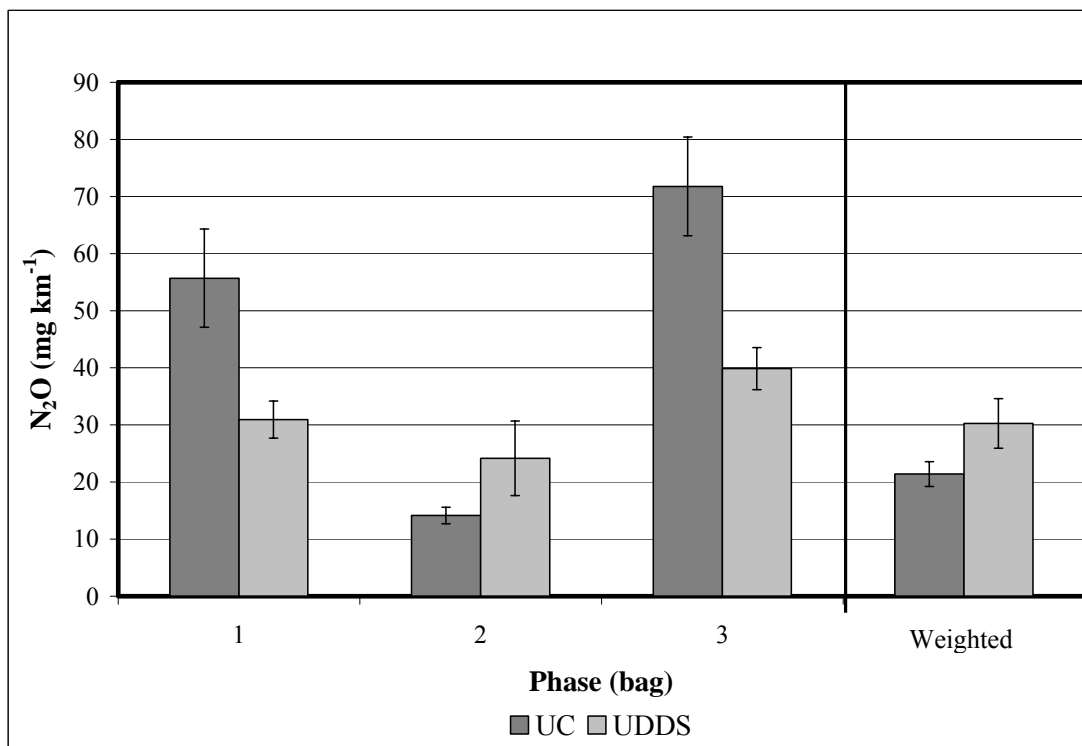


(a)

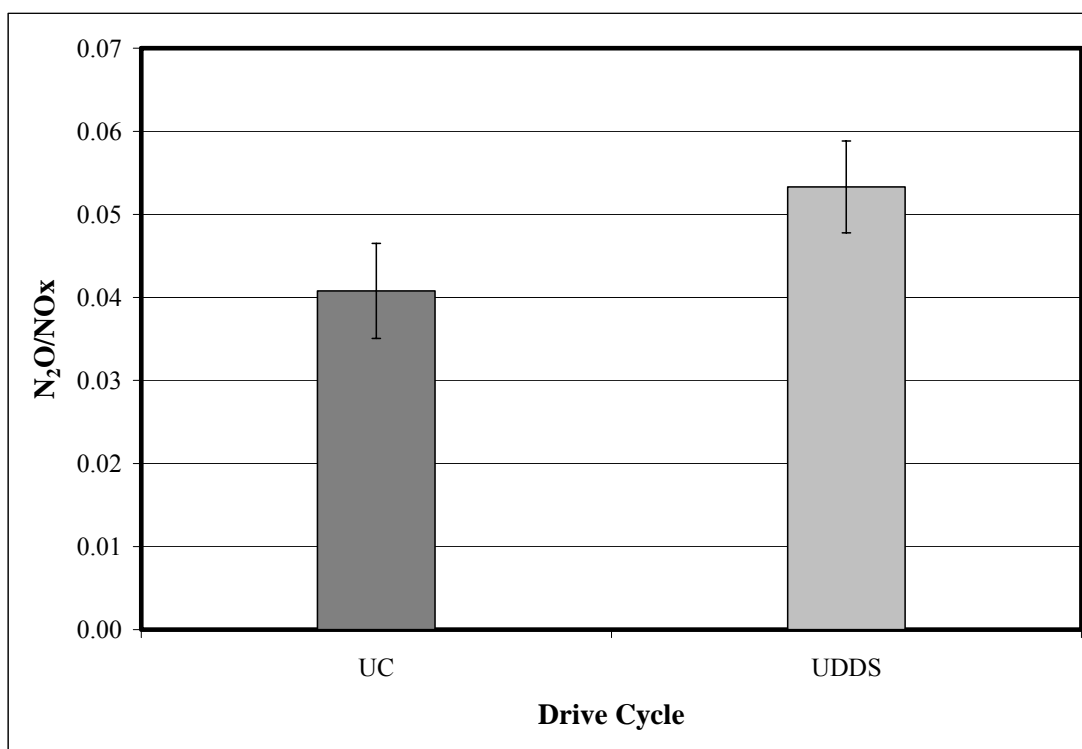


(b)

Figure 6.6. (a) Effect of catalyst type on N₂O emissions. (b) Effect of catalyst type on N₂O/NO_x emissions ratios. Sample of 38 experiments (36 for TWC and 2 for oxidation catalyst).



(a)



(b)

Figure 6.7. (a) Effect of driving cycle on N₂O emissions. (b) Effect of driving cycle on N₂O/NO_x emissions ratios. Sample of 57 experiments (21 for UC and 36 for UDDS cycle).

6.3.3. *Effect of Vehicle Type*

As shown in Figure 6.5, to evaluate the effect of vehicle type on N₂O emissions we used the following test vehicle configuration: TWC/TIER0/UDDS. Based on these characteristics, 49 vehicles were available to calculate the mean emissions during each of the three phases as well as the mean weighted emission factors for the different vehicle types. Figure 6.8a summarizes these results and shows vehicle type played a significant role in determining nitrous oxide emissions from the tested fleet. Specifically, for all three phases, light-duty trucks exhibited higher N₂O emissions compared to passenger vehicles. These results are in agreement with those of our pilot study.

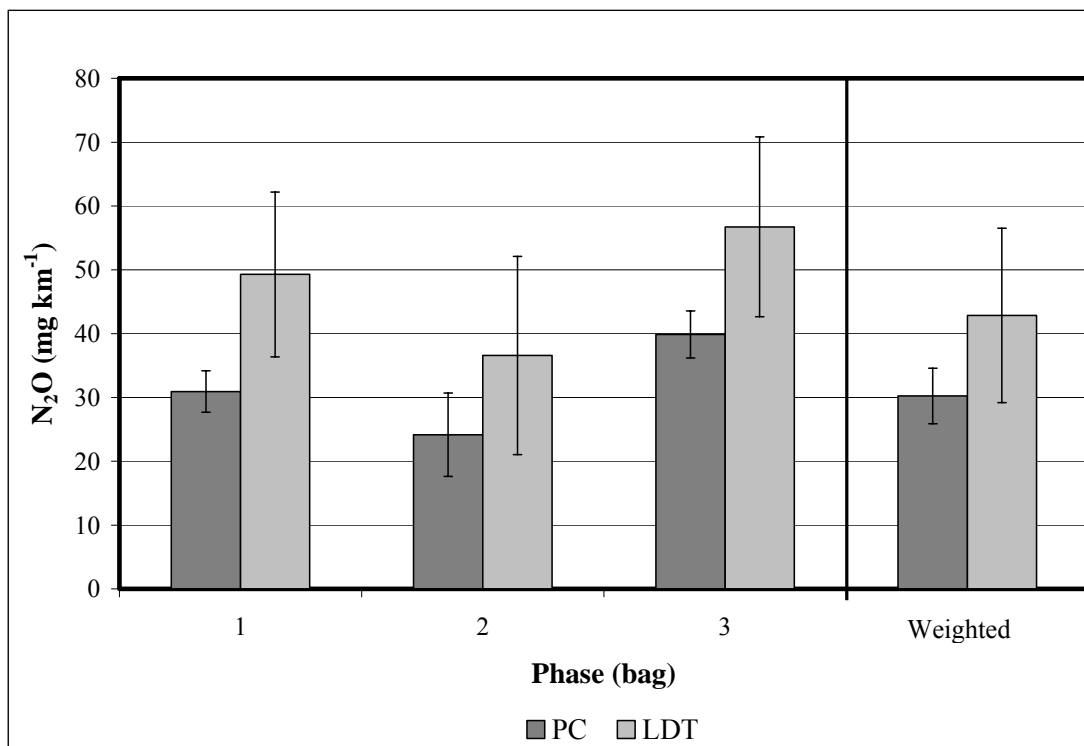
As shown in Figure 6.8b, for vehicle type, contrary to what was observed for catalyst type and driving cycle, N₂O/NO_x emissions ratios exhibited the opposite pattern to that observed for N₂O emissions. In this case, the N₂O/NO_x ratios were higher for passenger cars than for light-duty trucks. As further discussed in Section 6.3.5, these results provide part of the evidence demonstrating the inappropriateness of using tailpipe N₂O/NO_x emissions ratios for inventory development purposes.

6.3.4. *Effect of Emissions Standard*

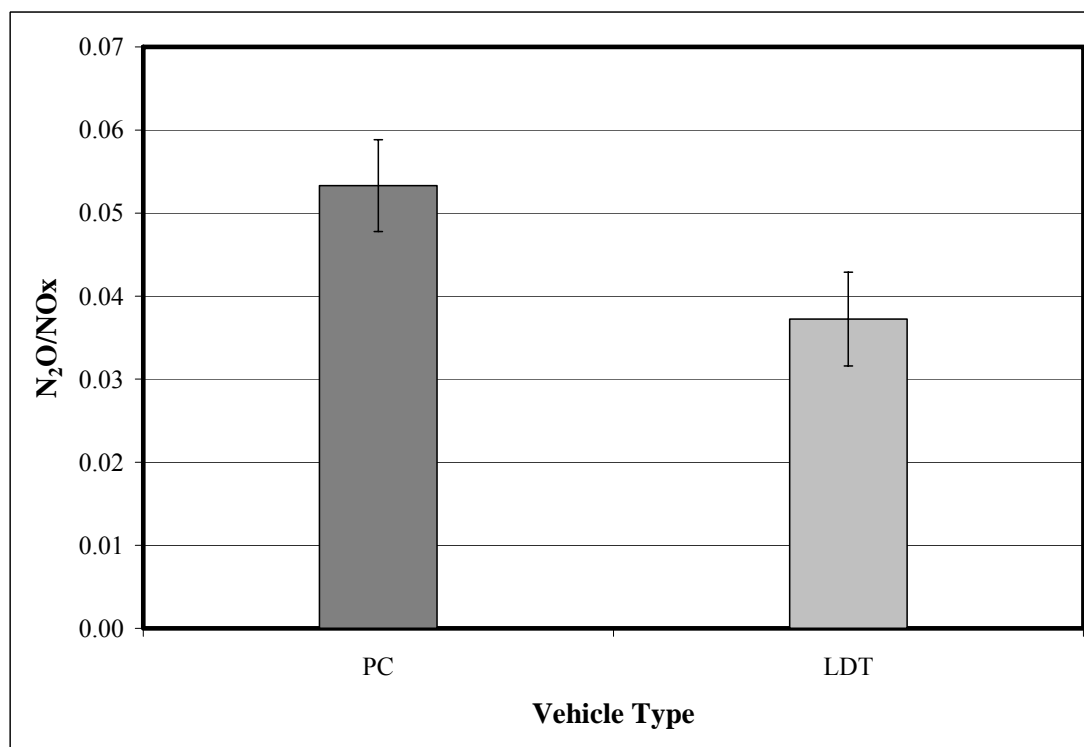
As depicted in Figure 6.5, to evaluate the effect of emissions standard on N₂O emissions we used the following test vehicle configuration: PC/TWC/UDDS. 82 vehicles met this configuration and were used to calculate the mean emissions during each of the three phases as well as the mean weighted emission factors for the different emission standards. Figure 6.9a summarizes these results.

Cold-start N₂O emissions followed a general trend consistent with increasingly stringent emission standards. During this phase, emissions from vehicles associated with more stringent standards were, in general, lower than those emissions from vehicles associated with less stringent standards (e.g., TIER0). Similarly, hot-stabilized and hot-start emissions were much higher for TIER0 vehicles than for TIER1, TLEV, and LEV vehicles, with comparable emissions from TIER1, TLEV, and LEV vehicles. Figure 6.9a also shows mean weighted emissions factor patterns were similar to those observed during the hot-stabilized and hot-start phases (i.e., highest emissions for TIER0 vehicles and comparable emissions for TIER1, TLEV, and LEV vehicles).

The results presented in Figure 6.9a demonstrate that emissions standard was the factor with the largest influence on N₂O emissions among all variables analyzed during the study of our integrated dataset. In Section 5.3.4, we discussed that on a real-time basis, catalyst temperature was the most important factor determining nitrous oxide emissions. These two results are related since more stringent emission standards have resulted in the introduction of more efficient catalytic converters that are able to more rapidly reach high operational temperatures.

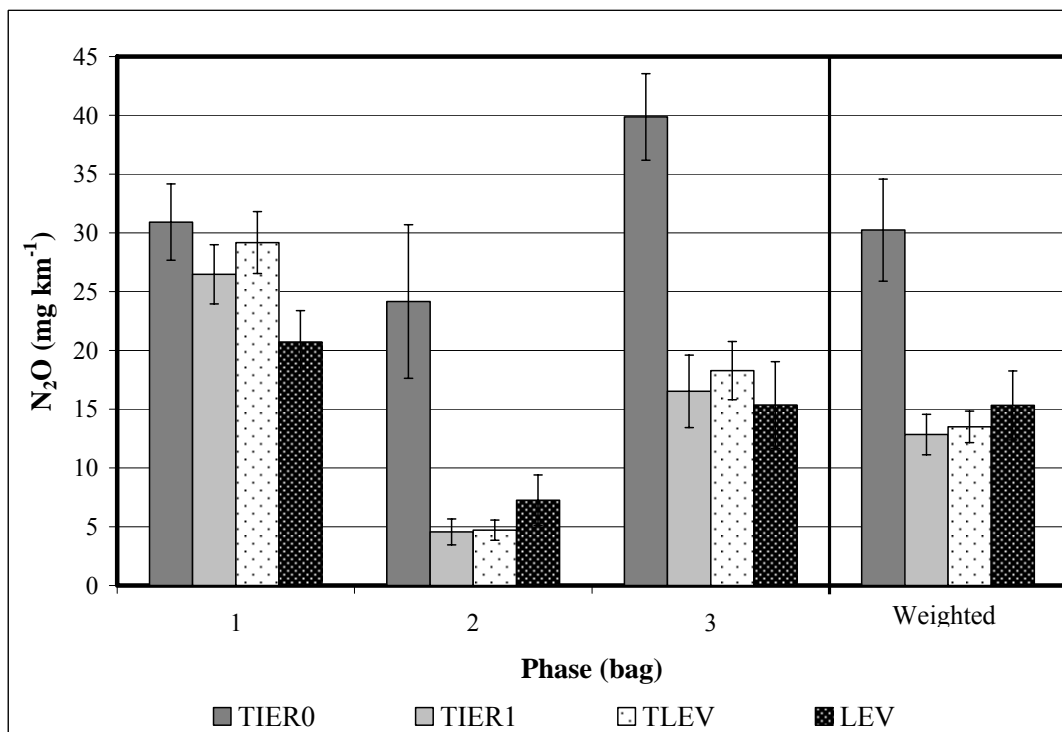


(a)

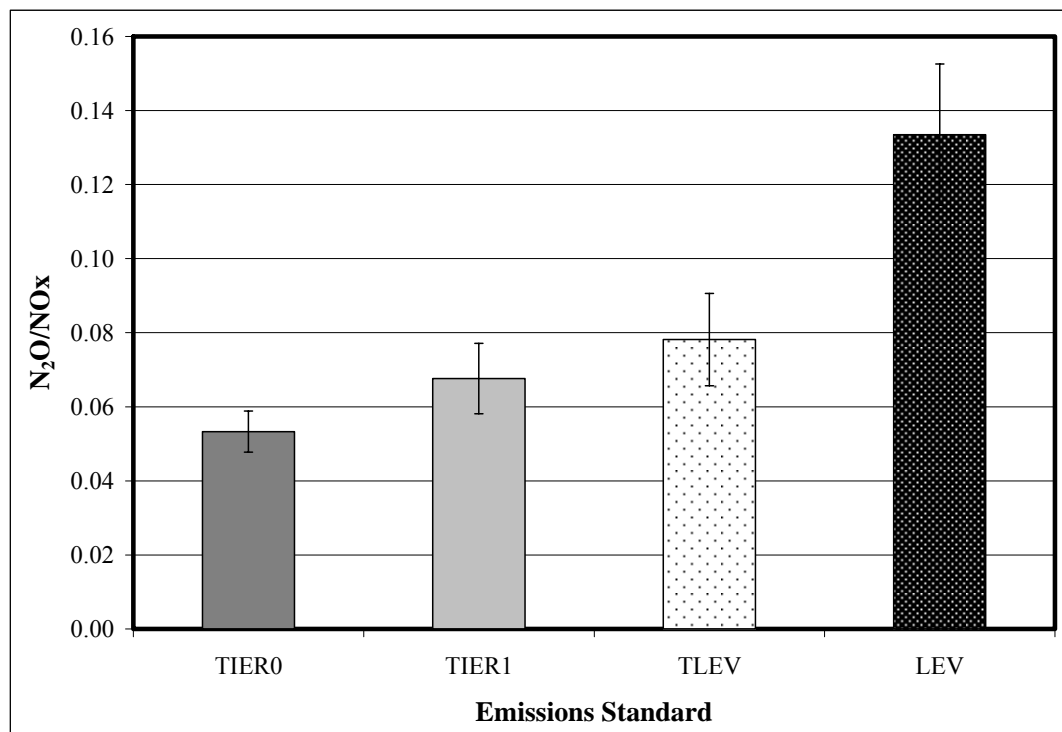


(b)

Figure 6.8. (a) Effect of vehicle type on N₂O emissions. (b) Effect of vehicle type on N₂O/NO_x emissions ratios. Sample of 49 experiments (13 for PC and 36 for LDT).



(a)



(b)

Figure 6.9. (a) Effect of emissions standard on N₂O emissions. (b) Effect of emissions standard on N₂O/NO_x emissions ratios. Sample of 82 experiments (36 for TIER0, 16 for TIER1, 14 for TLEV, and 16 for LEV).

Figure 6.9b shows N₂O/NO_x emissions ratios increased as emission standards became more stringent. These results suggest an inconsistency with the discussion presented in Section 5.3.7 regarding the evaluation of catalysts performance in terms of their capability to reduce nitrogen oxides without producing nitrous oxide as an intermediate. This apparent inconsistency is resolved by realizing the N₂O/NO_x ratios above refer to tailpipe (after the catalyst) emissions while the results in Section 5.3.7 refer to engine-out (before the catalyst) emissions.

6.3.5. *Implications of N₂O/NO_x Emissions Ratio Results*

One of the conclusions of our pilot study was that overall N₂O/NO_x emissions ratios and overall NO_x emissions could be used to roughly estimate N₂O emission factors for the tested fleet. Although this is valid in statistical terms, it is important to consider the real meaning of these ratios. Tailpipe N₂O/NO_x emissions ratios cannot be considered to be a measure of a catalyst's ability to reduce nitrogen oxides. High tailpipe N₂O/NO_x emissions ratios may be the result of two different conditions: (1) a well-performing catalyst installed in a vehicle with high NO_x engine-out emissions; and (2) an under-performing catalyst installed in a vehicle with relatively low NO_x engine-out emissions. In the first case, there will be relatively high N₂O production due to the large amount of NO_x being reduced with relatively low tailpipe NO_x emissions due to the efficient reduction. In the second case, there will be high production of N₂O due to low catalyst temperatures and relatively low NO_x tailpipe emissions (since NO_x levels were already low before the catalyst).

Figure 6.9b shows a more defined example of the conflicting information provided by tailpipe N₂O/NO_x emissions ratios. In this case, LEV vehicles equipped with more efficient control technologies and producing about half of the N₂O emissions produced by TIER0 vehicles (see Figure 6.9a) exhibited tailpipe N₂O/NO_x emissions ratios about 2.5 times higher than those for TIER0 vehicles. The reason for these elevated N₂O/NO_x ratios was the high efficiency of the vehicles' catalysts that resulted in very low NO_x tailpipe emissions. Therefore, in this case, high N₂O/NO_x ratios were an indication of efficient catalytic reduction. This is in contrast to the other possible interpretation (see Section 5.3.7) in which high N₂O/NO_x ratios would indicate poor catalyst performance where, as a consequence of low catalyst temperatures, more N₂O molecules were being produced by molecule of NO_x being reduced.

In summary, our results demonstrate tailpipe N₂O/NO_x emissions ratios can only be used as a first-order approximation model for fleets that are similar in composition to the fleet for which the ratios were measured. These ratios could be used to extrapolate N₂O emissions from one fleet to another and for emissions forecasting and backcasting but only after equivalence, in terms of the fleets' emissions standards, is established. For example, during our pilot study of 37 vehicles and 68 experiments we found an overall mean N₂O/NO_x emissions ratio of 0.09, whereas the complete dataset for 134 vehicles and 264 experiments used during the main study yielded an overall mean N₂O/NO_x emissions ratio of 0.06.

The real measure of catalyst efficiency, other than catalyst temperature, is the ratio of nitrous oxide emissions to the difference between engine-out and tailpipe NO_x emissions (see Section 5.3.7). However, it is not generally feasible to collect the latter information during in-use vehicle testing programs.

Figure 6.10 shows the distribution of N₂O/NO_x tailpipe emissions ratios for the tested fleet. The median ratio was 0.05 and the mean ratio, as mentioned above, was 0.06 (N = 264, σ = 0.05). The highest ratio was 0.32 and the lowest ratio was 0.005. Consistent with the results from Figure 6.9b and the discussion above, all N₂O/NO_x tailpipe emissions ratios above 0.20 corresponded to LEV vehicles and 21 of the top 25 N₂O/NO_x ratios were obtained when testing LEV vehicles.

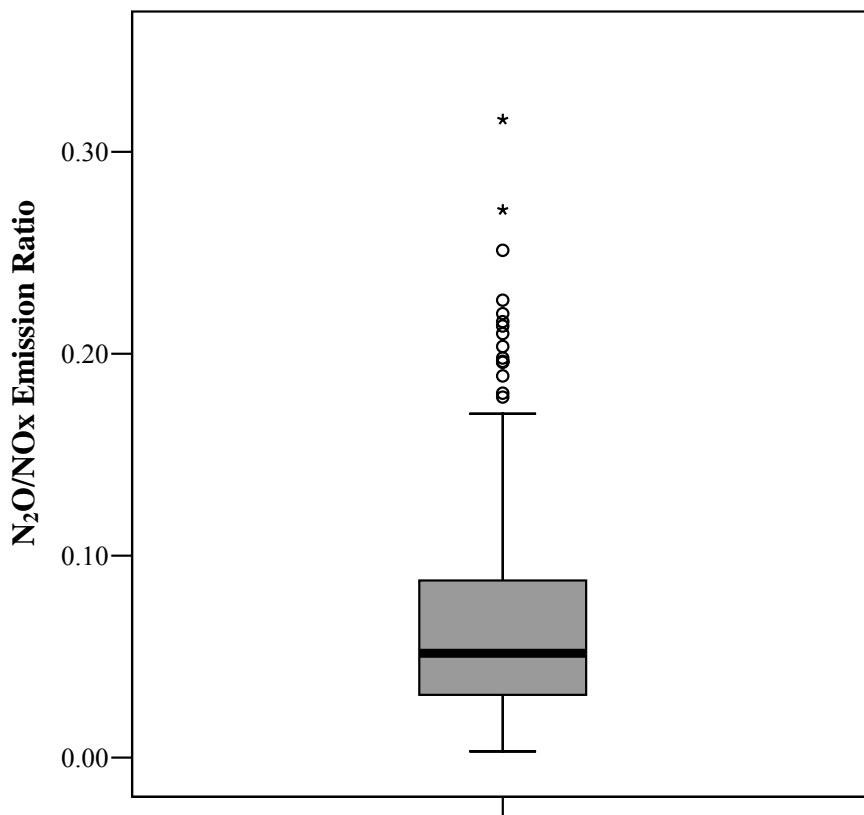


Figure 6.10. N₂O/NO_x tailpipe emission ratios of the tested fleet.
(See Appendix C for box plot schematic and description)

6.3.6. Correlation between Odometer Readings and N₂O Emissions

As mentioned in Section 4.1.1, the peer-reviewed literature contains conflicting data regarding the correlation between odometer readings and N₂O emissions. Neither during our pilot study nor during the main study were we able to determine a significant correlation between these two factors. However, this does not mean such a correlation does not exist. This only means data from in-use testing programs are not appropriate to establish such a correlation. Variables such as vehicle type and emission standards acted as confounding factors during our study and the addition of a new level to our filtering/binning process for odometer readings (Figure 6.5) produced small sample sizes that yielded non-statistically significant results. In addition, given the characteristics of the California fleet reflected in the testing program that was the source of our data, we did not test enough low-mileage or high-mileage vehicles for this type of analysis.

Figure 6.11 depicts a scatter plot between odometer readings and weighted N₂O emissions for all integrated sample experiments conducted during our study. The overall correlation was quite low ($r^2 < 0.1$) due to the confounding effects mentioned above. For example, for the seven experiments with higher-than-average N₂O emissions included in Box A in Figure 6.11, five corresponded to light-duty trucks and six were for TIER0 pre-1994 vehicles tested under the UDDS cycle. As discussed elsewhere, vehicle type, emissions standard, and driving cycle were factors which significantly affected N₂O emissions.

Although it cannot be quantitatively determined using data from in-use vehicle testing programs, there is a correlation between odometer readings (a proxy for catalyst age in most cases) and N₂O emissions. During our project, all vehicles with N₂O emission factors above 100 mg km⁻¹ had at least 190,000 kilometers on their odometers and all vehicles with N₂O emission factors below 2 mg km⁻¹ had less than 50,000 kilometers on their odometers. In addition, it is well documented that catalyst aging increases emissions of criteria pollutants such as CO and NO₂ and according to our results (see Section 5.3.3), high CO and NO₂ emitter vehicles were also high nitrous oxide emitters.

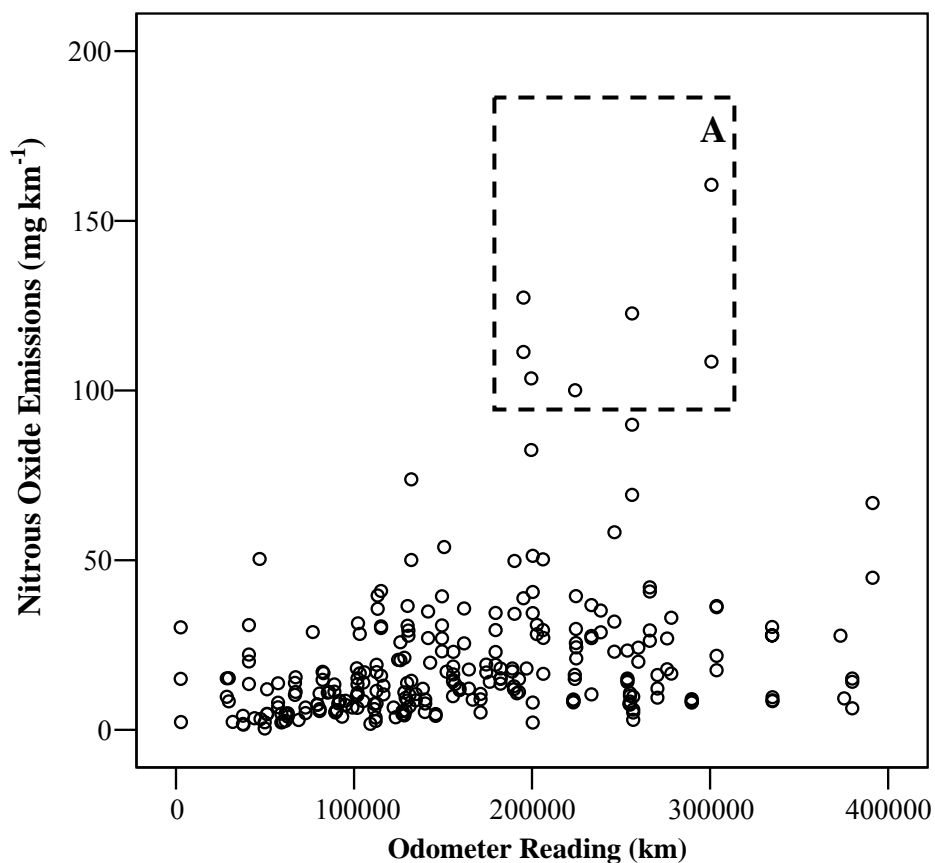


Figure 6.11. Scatter plot of N₂O emissions and odometer readings.

6.4. Overall Nitrous Oxide Emission Factors

Figure 6.12 summarizes the N₂O emissions obtained for our tested fleet. In addition to the mean emission factors, this figure shows three types of emission factor ranges: the absolute range of emission factors (between the minimum and the maximum observed), the range comprised between one standard deviation from the mean emission factors, and the 95% confidence interval of the mean emission factors. This figure also indicates the number of dynamometer tests that were used to establish these ranges (see numbers within parentheses in the column at the left of the diagram).

The approach used here to estimate typical emission factors is different to the one explained in Section 6.3 (analysis of variables affecting N₂O emissions), where the most important confounding factors were controlled by a data filtering process. For the following analyses, we use overall emission factors estimated combining all vehicles and tests according to the categories depicted in Figure 6.12.

Although the results presented in Figure 6.12 were obtained using overall emission factors without controlling for confounding factors, the overall trends were similar to those reported in Section 6.3, except for type of catalyst. TIER0 vehicles exhibited N₂O emission factors higher than TIER1, TLEV, and LEV vehicles. Light-duty trucks exhibited higher emission factors than passenger cars, and vehicles tested under the UDDS cycle yielded higher N₂O emissions than vehicles tested under the Unified Cycle.

Given the characteristics of California's in-use vehicle fleet, the sample of vehicles recruited for this study (a sub sample of the last two vehicle surveillance programs) only had a total of nine vehicles equipped with oxidation catalysts. The larger uncertainty caused by this limited sample size is reflected in the larger ranges presented in Figure 6.12 for overall N₂O emission factors for the two types of catalyst considered here.

It may appear at first that oxidation catalysts should not produce significant amounts of N₂O since the reactions that have been proposed to explain the catalytic formation of N₂O (see Section 2.4) imply the presence of rhodium in three-way catalysts and the resultant ability to reduce engine-out nitrogen oxides are the dominant factors determining such production. However, according to our results, vehicles equipped with oxidation catalysts could be important contributors to the N₂O mobile source emissions inventory. This could be explained by the fact that other precious metals present in an oxidation catalyst (platinum, palladium) have a limited ability to reduce nitrogen oxides. In addition, oxidation catalysts operate at lower temperatures compared to TWC, providing an environment that may enhance the production of nitrous oxide.

N₂O (mg km⁻¹)

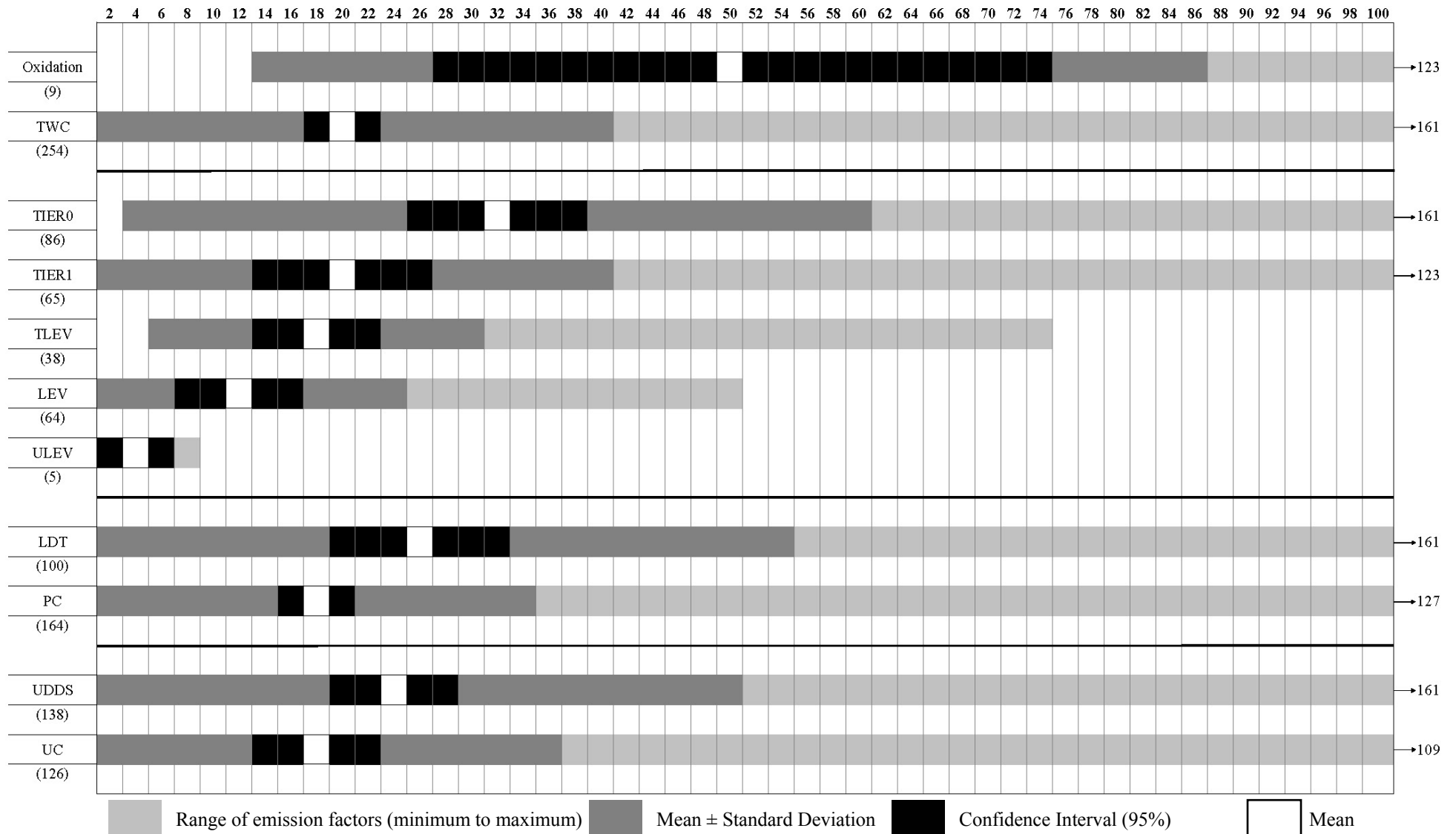


Figure 6.12. Nitrous oxide emissions factors from light-duty motor vehicles.

7. MEASUREMENTS OF AMMONIA EMISSIONS: METHOD DEVELOPMENT

7.1. Introduction

The contribution of unregulated compounds is becoming increasingly important in understanding the overall impact of vehicle emissions on air quality. Ammonia, in particular, is related to the formation of increased levels of secondary particulate matter in the atmosphere and recent experimental work has shown that ammonia emissions from vehicles may be more significant than previously reported, due in part to the complexity associated with the measurements of this compound. Thus, to accurately determine the emissions of ammonia from motor vehicles it is necessary to first develop a reliable and robust analytical method.

Due to its instability (caused by adsorption and permeation phenomena) when collected in Tedlar bags, ammonia exhaust concentrations must be analyzed using a real-time methodology. Real-time measurements of ammonia using FTIR on CVS-dilute exhaust have yielded promising results but there is still evidence of ammonia absorption and/or adsorption and carryover in the CVS system and related surfaces. The carryover of ammonia between phases during dynamometer test could lead to serious measurement errors when calculating the composite emissions for a test because the different phases have different weightings. Furthermore, real-time emissions from the same vehicle have shown a large (above 50%) test-to-test variability, which may be due to wall losses in the dilution tunnel or the FTIR cell. Real-time nitrous oxide emissions, which are prone neither to absorption nor to adsorption in the tunnel surfaces, do not show this type of test-to-test variability.

The purpose of the methodology developed during this part of the study was a) to identify and quantify the limitations of the real-time FTIR technique for ammonia analyses and b) find ways to improve the technique in order to design a reliable testing procedure that could become the standard method to determine ammonia emission factors from light-duty gasoline powered vehicles.

During this part of the project, we worked in close collaboration with staff from ARB's MLD and MSOD. Together, we designed a comprehensive experimental matrix that included 50 real-time experiments requiring careful planning as well as complex preparation (see Appendix E). During the design of this testing program, we considered the variables deemed to have a significant effect on ammonia recovery rates and ammonia wall losses in the testing system, including CVS flow rates (residence time), dilution air temperatures, and sampling line temperatures.

In this report, we do not present any comprehensive ammonia-related analyses as this was beyond the scope of our N₂O project report. However, a complete database containing the validated results obtained during the ammonia testing program has been provided to ARB as a separate deliverable. For more information please contact ARB's Organic Analysis Section.

7.2. Methods

7.2.1. *Ammonia Recovery*

The first step in the development of the procedure for determination of ammonia concentrations in automotive exhaust by FTIR spectroscopy for vehicles tested according to the FTP procedure (CFR, title 40), using a chassis dynamometer and a constant volume sampler, was to establish the ammonia recovery rates in the testing system. This was important because due to its polarity and solubility in water, ammonia may be absorbed and/or adsorbed on sampling tunnel surfaces. For this purpose, we conducted a series of ammonia recovery experiments to quantify the amount of ammonia that is lost between the tailpipe and the FTIR cell, as well as to determine the factors that affect such losses.

Before the recovery tests were conducted, it was necessary to condition the lines that were used to transport the NH₃ from a pressurized high-concentration standard cylinder to the CVS, as well as to condition the internal surfaces of the mass flow controller used to determine the amount of ammonia being injected.

During the ammonia recovery experiments, we injected a known amount of NH₃, from the standard cylinder, into the hose that is used to transport the exhaust gases from the tailpipe to the mixing tee. The NH₃ mixed with the dilution air and passed through an insulated line between the mixing tee and the CVS, and then through a heated line to the FTIR cell.

Once the ammonia was diluted in the CVS, the concentrations in the mixture were at ppm levels, similar to those present in vehicle exhaust. Ammonia is lighter than air, therefore, once the diluted air was released to the atmosphere there was no risk of contamination of the air conditioned intakes located at the roof of the laboratory building.

During this part of the ammonia testing program, we conducted the following sequence of experiments, performed at a CVS flow rate of 490 scfm (see Appendix E):

- Injection of NH₃, with dilution air and sampling line at ambient temperatures.
- Injection of NH₃, with dilution air at 105° F and sampling line at ambient temperature.
- Injection of NH₃, with dilution air at ambient temperature and sampling line at 105° F.
- Injection of NH₃, with dilution air and sampling line at 105° F.

This experimental matrix was used without a vehicle connected to the system and also while a vehicle was being tested under a modified version of the FTP-UDDS cycle, which included the first two phases of the UDDS cycle after the test vehicle was warmed-up at a constant speed of 80 kph for 10 minutes. We will refer to this hot-start cycle as the “J cycle.”

7.2.2. *Dilute exhaust and Raw Exhaust*

In addition to the recovery experiments described above, and considering that many of the difficulties associated with the methods used for determining ammonia emissions from vehicles are related to wall losses in the dilution tunnel, we conducted a series of experiments to determine if an FTIR technique could be used to accurately measure mass ammonia emissions in *undiluted* motor vehicle exhaust.

A Nicolet Antaris FTIR instrument (operated and conditioned by staff from the Thermo Electro Corporation), equipped with a raw exhaust gas cell (0.4 liters), was used to measure ammonia emissions out of the tailpipe of a light-duty vehicle in parallel with MLD's Nicolet Magna FTIR, which was simultaneously measuring CVS-dilute exhaust from the same vehicle (see figure in Appendix E). The main goal of these experiments was to compare test-to-test variability of ammonia emissions between raw and dilute exhaust.

A secondary goal of these experiments was to determine if mass emissions of ammonia could be calculated from the raw exhaust data and reconciled with the dilute exhaust data. To calculate mass emissions using tailpipe data it is necessary to have real-time dilution ratio data. These real-time dilution factors could have been determined from the relative (raw/dilute) concentrations of CO₂ or some other accurately measured component (e.g., N₂O). However, the two FTIRs used a different scanning cycle and there was a time lag between the two instruments, caused by the different configurations (raw exhaust vs. dilute exhaust), making it quite challenging to identify comparable measurements.

7.2.2.1. Calibration Verification

Prior to the dual-FTIR experiments, we established the correlation between the concentrations measured by the two instruments for several species of interest, including NH₃, CO₂, CO, NO_x, and N₂O. We analyzed samples from standard cylinders (at different concentrations for each gas) in both instruments, using their real-time data collection modes, to verify their calibrations were comparable.

7.2.2.2. Data Collection Using a Steady-State Drive Cycle

To verify, once again, that the two instruments were behaving similarly, we conducted a series of real-time experiments using a catalyst-equipped vehicle dynamometer tested under a steady-state cycle at 80 kph, in order to minimize the number of variables involved. Results from the concentrations collected with the two FTIRs were then reconciled.

7.2.2.3. Data Collection Using a Transient Drive Cycle

The final set of experiments were comprised of a series of repeat tests conducted for a catalyst-equipped vehicle to determine repeatability of real-time concentration profiles and average emissions between the two FTIR instruments for ammonia and other species. These experiments were performed under the J cycle (see above) using a CVS flow rate of 490 scfm.

During these experiments, the Antaris FTIR instrument collected raw-exhaust data at three sampling locations: (a) before the catalyst in the tailpipe, (b) directly post-catalyst in the tailpipe, and (c) at the entrance port of the mixing tee. The second instrument (Magna FTIR) collected dilute exhaust data using ARB's current experimental setup for obtaining real-time nitrous oxide emissions (see Section 3.6).

7.3. Preliminary Results

In addition to ammonia, we compared the results obtained from the two FTIR devices for nitrous oxide and carbon dioxide, compounds which we have validated in the real-time mode on the Magna system. We observed a relatively high correlation between the concentrations of these species for both FTIR instruments (after considering the CVS's dilution factor), which indicated the Antaris (raw cell) system was functioning as expected.

In addition, from the calibration crosschecks (see Section 7.2.2.1), a series of recovery experiments (see Section 7.2.1) using both FTIRs, and the steady-state experiments (see Section 7.2.2.2), we were able to determine the two FTIR instruments were producing comparable data for the transient drive cycle (see Section 7.2.2.3).

8. CONCLUSIONS, RECOMMENDATIONS, AND DATA AVAILABILITY

8.1. About our Methodology

The analysis of dilute exhaust samples by FTIR spectroscopy was demonstrated to be a robust and convenient technique for both integrated (bag) samples and real-time samples. Once the analytical method was developed, the instrument required little maintenance and was in compliance with all of our quality control criteria throughout the course of the study.

Given the complexity of the N₂O formation processes and the multiple variables involved, the data binning/filtering procedure we used to control for confounding factors during comparative analyses proved to be necessary to produce significant results.

8.2. Variables Affecting N₂O Emissions

Catalyst temperature is the single most important factor determining N₂O emissions from light-duty gasoline powered vehicles. Other relevant variables include type of vehicle, driving cycle (driving conditions), and applicable emissions standard. Table 7.1 summarizes the effect of these variables on N₂O emissions after controlling for confounding factors. Light-duty trucks exhibited higher N₂O emissions than passenger cars, vehicles tested under the UDDS yielded higher N₂O emissions than vehicles tested under the UC, and TIER0 (non-LEV) vehicles exhibited higher emissions than LEV-certified vehicles.

Table 8.1. Effect of several variables on N₂O emissions.

Variable	Change
Type of vehicle (LDT vs. PC)	+ 40 %
Driving cycle (UDDS vs. UC)	+ 70 %
Emissions Standard (TIER0 vs. LEV)	+ 100 %

Although it cannot be quantitatively determined using data from in-use vehicle testing programs, due to the presence of uncontrollable confounding factors and the lack of an appropriate range of values (not enough low-mileage or high-mileage test vehicles), a correlation was established between odometer readings (a proxy for catalyst age in most cases) and N₂O emissions. During our project, all vehicles with N₂O emission factors above 100 mg km⁻¹ had at least 190,000 kilometers on their odometers and all vehicles with N₂O emission factors below 2 mg km⁻¹ had less than 50,000 kilometers on their odometers (2 and 100 mg km⁻¹ were statistical extremes in our sample of vehicles).

8.2.1. *N₂O Emissions Modeling*

Nitrous oxide emissions modeling was not part of the scope of this project. However, based on our analyses, we determined N₂O emissions are a function of the following criteria: presence and type of catalytic converter in the vehicles, catalyst temperature, catalyst performance and age, fuel properties, applicable emission standards, driving cycle speed and accelerations, and vehicle class. Any effort made to model N₂O emission should consider these criteria as a minimum.

8.3. Catalyst Temperature

High catalyst temperatures (> 650 °F) were associated with lower N₂O emission factors and vice versa. For example, the difference depicted in Table 7.1 between N₂O emissions from vehicles tested under the UC and UDDS cycle, is explained by the lower temperatures observed during UDDS tests. Similarly, the difference between LEV and TIER0 vehicles presented in Table 7.1, is explained by the introduction of more efficient catalytic converters (as a result of more stringent emission standards), which are able to rapidly reach high operational temperatures that yield lower N₂O emissions.

In addition, real-time N₂O emission patterns were closely related to catalyst temperatures. For example, the differences in timing and magnitude for N₂O real-time concentration spikes between the vehicle categories we studied were related to the time required for the catalysts to reach their operational temperatures. Catalyst warm-up periods for high N₂O emitting vehicles were longer than for low emitting vehicles.

Catalyst temperatures below 120 °C are not adequate for NO reduction. Hence, N₂O production is very limited under these conditions. N₂O catalytic formation is enhanced between 120 and 550 °C. Catalyst temperatures above 650 °C generate optimal conditions for the reduction of NO to N₂, resulting in negligible production of N₂O.

8.4. N₂O/NO Emissions Ratios

Overall tailpipe N₂O/NO_x emissions ratios and overall tailpipe NO_x emissions could be used to roughly estimate N₂O emission factors for fleets that are similar in composition to the fleet for which the ratios were measured. In addition, if equivalence between the fleets' emissions standards can be demonstrated, the N₂O/NO_x emissions ratios could be used for emissions backcasting and forecasting and also for extrapolation of N₂O emission factors between equivalent fleets. These tailpipe emissions ratios, however, cannot be deemed as a measure of catalyst efficiency or a proxy for the catalyst's ability to reduce nitrogen oxides without producing large quantities of N₂O. This type of information would only be provided by establishing the ratio (R) of tailpipe nitrous oxide emissions (N₂O_T) to the difference between engine-out (NO_E) and tailpipe NO_x emissions (NO_T). However, it is not be feasible to collect these data during in-use vehicle testing programs.

$$R = \frac{N_2O_T}{(NO_E - NO_T)} \quad (5)$$

8.5. N₂O Emission Factors

The median emissions factor for all the tests we conducted was 14 mg km⁻¹ and the mean emissions factor was 20 mg km⁻¹ (N = 264; σ = 22). As expected, these results were lower than those reported in previous research since the fleet tested in the present study included recent model-year vehicles equipped with efficient emission control technologies that resulted in lower N₂O emissions. This pattern of decreasing N₂O emissions from light-duty vehicles will continue with increasingly stringent emission standards.

There were eight extreme cases (emission factors above three times the interquartile range) in our sample. For the seven extreme cases exhibiting emission factors above 100 mg km⁻¹, five corresponded to large-engine displacement LDTs, six were for vehicles certified as TIER0 according to California emission standards, and six were for 1994 model-year or older vehicles. High N₂O emitting vehicles were also high emitters of NO, CO and CH₄, confirming these vehicles were equipped with ineffective catalytic converters. The four lowest weighted N₂O emission factors (less than 2 mg km⁻¹) were observed for 2001 LEV and ULEV passenger cars tested under the Unified Cycle. Table 7.2 summarizes the N₂O and NO_x emission factors for all test configurations used during this study.

8.6. Oxidation Catalysts

According to our results, vehicles equipped only with oxidation catalysts exhibited significant emissions of nitrous oxide. This could be explained by the fact that precious metals present in an oxidation catalyst (platinum, palladium) have a limited ability to reduce nitrogen oxides and hence they are able to produce nitrous oxide. In addition, oxidation catalysts operate at lower temperatures compared to TWC, providing conditions that may enhance the production of nitrous oxide. Such an effect, however, may be offset by the relatively low travel fraction of this type of vehicles, representing less than 2% of the total VMT in the state of California.

8.7. Recommendations

Mobile source nitrous oxide emissions are a consequence of the introduction of emission control technologies aimed at reducing criteria pollutants. Although modern catalysts and stringent emission standards have resulted in decreased N₂O emissions, the catalytic formation of this species provides an example of an environmental protection program that while addressing one problem is also causing a negative impact. This demonstrates the importance of a comprehensive analysis when implementing technical approaches to reducing pollutant emissions

Long lifetime catalysts will result in decreased N₂O emissions since, similar to other exhaust species, these emissions depend on the overall performance of the catalytic converter.

Improving traffic conditions will also result in lower N₂O emissions since hot-stabilized operating conditions, in which high catalyst temperatures are sustained for relatively long periods of time while no extreme acceleration events are present, result in improved catalyst performance and decreased N₂O emissions.

Table 8.2. N₂O emission factors.

Test Configuration	N ₂ O (mg km ⁻¹)	NO _x (mg km ⁻¹)	Number of vehicles tested
PC, TWC, TIER0 ¹ , UC	20	700	16
PC, TWC, TIER0 ¹ , UDDS	30	650	27
PC, TWC, TIER1 ¹ , UC	12	340	12
PC, TWC, TIER1 ¹ , UDDS	13	250	15
PC, TWC, TLEV, UC	12	260	11
PC, TWC, TLEV, UDDS	13	215	14
PC, TWC, LEV, UC	9	140	24
PC, TWC, LEV, UDDS	15	160	14
PC, TWC, ULEV, UC	0.5	35	1
PC, TWC, ULEV, UDDS	2	35	1
PC, Oxidation, TIER0 ¹ , UC	23	1300	2
PC, Oxidation, TIER0 ¹ , UDDS	22	800	2
LDT, Oxidation, TIER0 ¹ , UC	40	1700	1
LDT, Oxidation, TIER0 ¹ , UDDS	35	950	1
LDT, Oxidation, TIER1 ¹ , UC	80	1700	2
LDT, Oxidation, TIER1 ¹ , UDDS	120	1200	1
LDT, TWC, TIER0 ¹ , UC	35	1400	9
LDT, TWC, TIER0 ¹ , UDDS	43	1000	11
LDT, TWC, TIER1 ¹ , UC	18	600	13
LDT, TWC, TIER1 ¹ , UDDS	20	420	14
LDT, TWC, TLEV, UC	25	550	7
LDT, TWC, TLEV, UDDS	25	500	6
LDT, TWC, LEV, UC	12	150	12
LDT, TWC, LEV, UDDS	15	150	12
LDT, TWC, ULEV, UC	4	110	2
LDT, TWC, ULEV, UDDS	5	85	1

¹ Non-LEV vehicles. These terms refer to federal emission standards (see Section 2.6).

8.8. Data Availability

The data collected during the experiments conducted as part of this study were validated, organized, and condensed into one database before the analyses reported in this document were performed. These data, considered data for record (DFR), have also been delivered to MSOD to be uploaded to ARB's Vehicle Testing System (VTS) database and will be available to ARB's employees with access privileges. For more information please contact ARB's MSOD.

9. RECOMMENDATIONS FOR FUTURE RESEARCH

As mentioned earlier, the breadth of the vehicle sample selected for past and current in-use vehicle testing programs has not been adequate to determine the correlation between catalyst mileage (a measure of catalyst age) and N₂O emissions. Efforts should be made to further quantify the effect of catalyst aging on N₂O emissions using vehicles from in-use fleets with extremes of both high and low mileage vehicles.

Several published studies have discussed the potential use of N₂O/NO_x ratios for emission estimations and forecasting. As discussed in this report, these ratios are of limited applicability and can be used for such purposes only under specific circumstances. More testing involving engine-out emissions should be conducted to better understand the applicability of these emissions ratios.

Catalyst precious metal contents are likely to play a significant role in determining N₂O emissions from light-duty vehicles. Further testing involving substrate analyses should be conducted to understand this effect.

The FTIR technique we used for determining N₂O concentrations in dilute exhaust samples is limited when testing high CO emitters due to interference from CO absorption bands. This effect may also affect the accuracy during real-time testing and makes N₂O measurements from raw exhaust samples difficult. Efforts should be made to develop a technique to eliminate CO from exhaust samples without affecting the N₂O concentrations.

Given the relatively complex and expensive methods required for a large-scale N₂O emissions testing program, efforts should be made to develop a methodology to use ARB's current N₂O emissions database, as presented in this report, to estimate N₂O emission factors for other regions of the U.S. and abroad with less economic resources where such data are not likely to be available.

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11. INVENTIONS REPORTED AND COPYRIGHT MATERIAL PRODUCED

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12. APPENDICES

- Appendix A. California exhaust emission standards
- Appendix B. N₂O real-time experiments
- Appendix C. Box plot schematic and description
- Appendix D. N₂O concentrations from integrated exhaust samples
- Appendix E. Ammonia real-time experiments

APPENDIX A

CALIFORNIA EXHAUST EMISSION STANDARDS

**Source: California exhaust emission standards and test procedures for 1988-2000 model passenger cars, light-duty trucks, and medium-duty vehicles
– Pages 3-1 to 3-15 –**

<http://www.arb.ca.gov/msprog/levprog/cleandoc/ldvtp88.pdf>

3. Standards

The following standards, with the exception of standards in Section 3.m., represent the maximum projected exhaust emissions for the useful life of the vehicle. The standards in Section 3.m. represent the maximum Supplemental Federal Test Procedure exhaust emissions at 4,000 miles \pm 250 miles or at the mileage determined by the manufacturer for emission-data vehicles, according to 40 CFR 86.090-26 as modified by these test procedures.

a. The exhaust emissions from new 1988 model passenger cars, light-duty trucks, and medium-duty vehicles shall not exceed:

1988 EXHAUST EMISSIONS STANDARDS^{5,6} (grams per mile)

<i>Vehicle Type¹</i>	<i>Loaded Vehicle Weight (lbs.)</i>	<i>Durability Vehicle Basis (mi)</i>	<i>Non-Methane Hydrocarbons²</i>	<i>Carbon Monoxide</i>	<i>Oxides of Nitrogen³</i>
PC	All	50,000	0.39 (0.41)	7.0	0.4
PC ⁴	All	50,000	0.39 (0.41)	7.0	0.7
PC (Option 1)	All	100,000	0.39 (0.41)	7.0	1.0
PC (Option 2)	All	100,000	0.46	8.3	1.0
LDT,MDV	0-3750	50,000	0.39 (0.41)	9.0	0.4
LDT,MDV ⁴	0-3750	50,000	0.39 (0.41)	9.0	1.0
LDT,MDV (Option 1)	0-3750	100,000	0.39 (0.41)	9.0	1.0
LDT,MDV (Option 2)	0-3750	100,000	0.46	10.6	1.0
LDT,MDV	3751-5750	50,000	0.50 (0.50)	9.0	1.0
LDT,MDV (Option 1)	3751-5750	100,000	0.50 (0.50)	9.0	1.5
MDV	5751+	50,000	0.60 (0.60)	9.0	1.5
MDV (Option 1)	5751+	100,000	0.60 (0.60)	9.0	2.0

- (1) "PC" means passenger cars.
"LDT" means light-duty trucks.
"MDV" means medium-duty vehicles.
- (2) Hydrocarbon standards in parentheses apply to total hydrocarbons. In order to demonstrate compliance with a non-methane hydrocarbon emission standard, hydrocarbon emissions shall be measured in accordance with the "California Non-Methane Hydrocarbon Test Procedures."
- (3) The maximum projected emissions of oxides of nitrogen measured on the federal Highway Fuel Economy Test (HWFET; 40 CFR Part 600 Subpart B) shall be not greater than 1.33 times the applicable passenger car standards and 2.00 times the applicable light-duty trucks and medium-duty vehicle standards shown in the table. Both the projected emissions and the HWFET standard shall be rounded in accordance with ASTM E29-67 to the nearest 0.1 g/mi before being compared.

- (4) This set of standards for 1988 and later model vehicles is optional. A manufacturer may choose to certify to these optional standards pursuant to the conditions set forth in Section 1960.1.5 of Title 13, California Code of Regulations.
- (5) Diesel passenger cars, light-duty trucks, and medium-duty vehicles, except those fueled with methanol, are subject to the following particulate exhaust emission standards: 0.2 g/mi for the 1988 model years. The particulate compliance shall be determined on a 50,000 mile durability vehicle basis.
- (6) For gaseous-fueled vehicles the calculation procedures provided in Appendix V shall be used for determining emissions and fuel economy.

b. The exhaust emissions from (i) new 1989 through 1992 model passenger cars and light-duty trucks, except those produced by a small volume manufacturer, (ii) new 1991 through 1994 model passenger cars and light-duty trucks produced by a small volume manufacturer, (iii) new 1989 through 1994 model medium-duty vehicles, except those produced by a small volume manufacturer, and (iv) new 1991 through 1994 model medium-duty vehicles produced by a small volume manufacturer, shall not exceed:

1989 THROUGH 1994 MODEL YEAR EXHAUST EMISSIONS STANDARDS^{5,6}
(grams per mile)

<i>Vehicle Type¹</i>	<i>Loaded Vehicle Weight (lbs.)</i>	<i>Durability Vehicle Basis (mi)</i>	<i>Non-Methane Hydrocarbon²</i>	<i>Carbon Monoxide</i>	<i>Oxides of Nitrogen^{3,4}</i>
PC	All	50,000	0.39 (0.41)	7.0	0.4
PC ⁷	All	50,000	0.39 (0.41)	7.0	0.7
Diesel PC (Option 2)	All	100,000 ⁹	0.46	8.3	1.0
LDT,MDV	0-3750	50,000	0.39 (0.41)	9.0	0.4
LDT,MDV ⁷	0-3750	50,000	0.39 (0.41)	9.0	0.7 ⁸
Diesel LDT, MDV (Option 2)	0-3750	100,000 ⁹	0.46	10.6	1.0
LDT,MDV	3751-5750	50,000	0.50 (0.50)	9.0	1.0
LDT,MDV (Option 1)	3751-5750	100,000 ⁹	0.50 (0.50)	9.0	1.5
MDV	5751+	50,000	0.60 (0.60)	9.0	1.5
MDV (Option 1)	5751 +	100,000 ⁹	0.60 (0.60)	9.0	2.0

- (1) "PC" means passenger cars.
"LDT" means light-duty trucks.
"MDV" means medium-duty vehicles.
- (2) Hydrocarbon standards in parentheses apply to total hydrocarbons. In order to demonstrate compliance with a non-methane hydrocarbon emission standard, hydrocarbon emissions shall be measured in accordance with the "California Non-Methane Hydrocarbon Test Procedures." For 1993 through 1994 model methanol-fueled vehicles certifying to these standards, including fuel-flexible vehicles, "Non-Methane Hydrocarbons" shall mean "Organic Material Hydrocarbon Equivalent" (or "OMHCE").
- (3) The maximum projected emissions of oxides of nitrogen measured on the federal Highway Fuel Economy Test (HWFET; 40 CFR Part 600 Subpart B) shall be not greater than 1.33 times the applicable passenger car standards and 2.00 times the applicable light-duty trucks and medium-duty vehicle standards shown in the table. Both the projected emissions and the HWFET standard shall be rounded in accordance with ASTM E29-67 to the nearest 0.1 g/mi before being compared.
- (4) The standard for in-use compliance for passenger cars, light-duty trucks and medium-duty vehicles certifying to the 0.4 g/mi NOx standard shall be 0.55 g/mi NOx for 50,000 miles. If the in-use compliance level is above 0.4 g/mi NOx but does not exceed 0.55 g/mi NOx, and based on a review of information derived from a statistically valid and representative sample of vehicles, the Executive Officer determines that a substantial percentage of any class or category of such vehicles exhibits,

prior to 50,000 miles or 5 years, whichever occurs first, an identifiable, systematic defect in a component listed in Section 1960.1.5(c)(2), Title 13, California Code of Regulations, which causes a significant increase in emissions above those exhibited by vehicles free of such defects and of the same class or category and having the same period of use and mileage, then the Executive Officer may invoke the enforcement authority under Subchapter 2.5, Title 13, California Code of Regulations, commencing with Section 2111, to require remedial action by the vehicle manufacturer. Such remedial action shall be limited to owner notification and repair or replacement of the defective component. As used in this section, the term "defect" shall not include failures which are the result of abuse, neglect, or improper maintenance. This provision is applicable for the 1989 through 1992 model years only. For small volume manufacturers, this provision is applicable for the 1991 through 1994 model years only.

- (5) Diesel passenger cars, light-duty trucks, and medium-duty vehicles certifying to these standards are subject to a particulate exhaust emission standard of 0.08 g/mi for the 1989 and subsequent model years. The particulate compliance shall be determined on a 50,000 mile durability vehicle basis.
- (6) For gaseous-fueled vehicles certifying to these standards, the calculation procedures provided in Appendix V shall be used for determining emissions and fuel economy.
- (7) This set of standards is optional. A manufacturer may choose to certify to these standards pursuant to the conditions set forth in Section 1960.1.5 of Title 13, California Code of Regulations.
- (8) Pursuant to Section 1960.1.5(a)(1)(B), Title 13, California Code of Regulations the optional standard for 1989 model year light-duty trucks and medium-duty vehicles only is 1.0 g/mi NOx.
- (9) The optional 100,000 mile certification standards and provisions are not applicable to alcohol vehicles.

e. The exhaust emissions from new 1993 and 1994 model passenger cars and light-duty trucks, except those produced by a small volume manufacturer, shall not exceed:

**1993 AND 1994 MODEL-YEAR PASSENGER CAR AND LIGHT-DUTY TRUCK
EXHAUST EMISSIONS STANDARDS^{5,6,10}**
(grams per mile)

<i>Vehicle Type¹</i>	<i>Loaded Vehicle Weight (lbs)</i>	<i>Durability Vehicle Basis (mi)</i>	<i>Non-Methane Hydrocarbons^{2,8,9}</i>	<i>Carbon Monoxide^{8,9}</i>	<i>Oxides of Nitrogen^{1,3,4}</i>
PC	All	50,000	0.39 (0.25)	7.0 (3.4)	0.4
PC ⁷	All	50,000	0.39 (0.25)	7.0 (3.4)	0.7
PC	All	100,000	(0.31)	(4.2)	n/a
Diesel PC (Option 2)	All	100,000	0.46 (0.31)	8.3 (4.2)	1.0
LDT	0-3750	50,000	0.39 (0.25)	9.0 (3.4)	0.4
LDT ⁷	0-3750	50,000	0.39 (0.25)	9.0 (3.4)	0.7
LDT	0-3750	100,000	(0.31)	(4.2)	n/a
Diesel LDT (Option 2)	0-3750	100,000	0.46 (0.31)	10.6 (4.2)	1.0
LDT	3751-5750	50,000	0.50 (0.32)	9.0 (4.4)	1.0
LDT	3751-5750	100,000	(0.40)	(5.5)	n/a
Diesel LDT (Option 1)	3751-5750	100,000	0.50 (0.40)	9.0 (5.5)	1.5

- (1) "PC" means passenger cars.
"LDT" means light-duty trucks.
"n/a" means not applicable.
- (2) In order to demonstrate compliance with a non-methane hydrocarbon emission standard, hydrocarbon emissions shall be measured in accordance with the "California Non-Methane Hydrocarbon Test Procedures." For methanol-fueled vehicles certifying to these standards, including fuel-flexible vehicles when certifying on methanol, "Non-Methane Hydrocarbons" shall mean "Organic Material Hydrocarbon Equivalent" (or "OMHCE"). For alcohol vehicles certifying to the phase-in standards in parenthesis, including fuel-flexible vehicles when certifying on methanol or ethanol, "Non-Methane Hydrocarbons" shall mean "Organic Material Non-Methane Hydrocarbon Equivalent" (or "OMNMHCE").
- (3) The maximum projected emissions of oxides of nitrogen measured on the federal Highway Fuel Economy Test (HWFET; 40 CFR Part 600 Subpart B) shall be not greater than 1.33 times the applicable passenger car standards and 2.00 times the applicable light-duty truck and medium-duty vehicle standards shown in the table. Both the projected emissions and the HWFET standard shall be rounded in accordance with ASTM E29-67 to the nearest 0.1 g/mi before being compared.
- (4) The standard for in-use compliance for passenger cars and light-duty trucks certifying to the 0.4 g/mi NOx standard shall be 0.55 g/mi NOx for 50,000 miles. If the in-use compliance level is above 0.4 g/mi NOx but does not exceed 0.55 g/mi NOx, and based on a review of information derived from a statistically valid and representative sample of vehicles, the Executive Officer determines that a substantial percentage of any class or category of such vehicles exhibits, prior to 50,000 miles or 5 years, whichever occurs first, an identifiable, systematic defect in a component listed in Section

- 1960.1.5(c)(2), Title 13 California Code of Regulations, which causes a significant increase in emissions above those exhibited by vehicles free of such defects and of the same class or category and having the same period of use and mileage, then the Executive Officer may invoke the enforcement authority under subchapter 2.5, Title 13, California Code of Regulations, commencing with Section 2111, to require remedial action by the vehicle manufacturer. Such remedial action shall be limited to owner notification and repair or replacement of the defective component. As used in this section, the term "defect" shall not include failures which are the result of abuse, neglect, or improper maintenance. This provision is applicable for the 1993 model year only.
- (5) Diesel passenger cars and light-duty trucks certifying to these standards are subject to a particulate exhaust emission standard of 0.08 g/mi, determined on a 50,000 mile durability vehicle basis.
 - (6) For gaseous-fueled vehicles certifying to these standards, the calculation procedures provided in Appendix V shall be used for determining emissions and fuel economy.
 - (7) This set of standards is optional. A manufacturer may choose to certify to these standards pursuant to the conditions set forth in Section 1960.1.5 of Title 13, California Code of Regulations.
 - (8) The emission standards in parenthesis are phase-in standards. For the 1993 model year, each manufacturer must certify a minimum of 40% of their vehicles to the phase-in standards or to the more stringent standards in Section 3.g of these test procedures. The percentage shall be applied to the manufacturers' total projected sales of California-certified passenger cars and light-duty trucks for the 1993 model year. For 1994 and subsequent model years, manufacturers shall comply with the fleet average requirements specified in Section 3.h. of these test procedures.
 - (9) The following conditions shall apply to the in-use compliance standards of 1993 and 1994 model-year passenger cars and light-duty trucks only.
 - (a) The in-use compliance standards for those passenger cars and light-duty trucks certifying to the 0.25 g/mi non-methane hydrocarbon and 3.4 g/mi carbon monoxide standards shall be 0.32 g/mi non-methane hydrocarbon and 5.2 g/mi carbon monoxide for 50,000 miles.
 - (b) The in-use compliance standards for those light-duty trucks certifying to the 0.32 g/mi non-methane hydrocarbon and 4.4 g/mi carbon monoxide standards shall be 0.41 g/mi non-methane hydrocarbon and 6.7 g/mi carbon monoxide for 50,000 miles.
 - (c) In-use compliance standards shall be waived beyond 50,000 miles.
 - (10) All passenger cars and light-duty trucks, except those diesel vehicles certifying to optional 100,000 mile standards, are subject to non-methane hydrocarbon, carbon monoxide, and oxides of nitrogen standards determined on a 50,000 mile durability basis and non-methane hydrocarbon and carbon monoxide standards determined on a 100,000 mile basis.

f. The exhaust emissions from new 1995-2000 model Tier 1 passenger cars and light-duty trucks shall not exceed:

**1995-2000 MODEL-YEAR TIER 1 PASSENGER CAR AND
LIGHT-DUTY TRUCK EXHAUST EMISSIONS STANDARDS^{5,6,8,9,11}**
(grams per mile)

<i>Vehicle Type¹</i>	<i>Loaded Vehicle Weight (lbs)</i>	<i>Durability Vehicle Basis (mi)</i>	<i>Non-Methane Hydrocarbons^{2,7}</i>	<i>Carbon Monoxide⁷</i>	<i>Oxides of Nitrogen^{1,3}</i>
PC	All	50,000	0.25	3.4	0.4 ⁴
PC	All	100,000	0.31	4.2	0.6 ¹⁰
Diesel PC	All	100,000	0.31	4.2	1.0
(Option 2)					
LDT	0-3750	50,000	0.25	3.4	0.4 ⁴
LDT	0-3750	100,000	0.31	4.2	0.6 ¹⁰
Diesel LDT	0-3750	100,000	0.31	4.2	1.0
(Option 2)					
LDT	3751-5750	50,000	0.32	4.4	0.7
LDT	3751-5750	100,000	0.40	5.5	0.97 ¹⁰
Diesel LDT	3751-5750	100,000	0.40	5.5	1.5
(Option 1)					

- (1) "PC" means passenger cars.
"LDT" means light-duty trucks.
- (2) In order to demonstrate compliance with a non-methane hydrocarbon emission standard, hydrocarbon emissions shall be measured in accordance with the "California Non-Methane Hydrocarbon Test Procedures." For alcohol-fueled vehicles certifying to these standards, including fuel-flexible vehicles when certifying on methanol or ethanol, "Non-Methane Hydrocarbons" shall mean "Organic Material Non-Methane Hydrocarbon Equivalent" (or "OMNMHCE").
- (3) The maximum projected emissions of oxides of nitrogen measured on the federal Highway Fuel Economy Test (HWFET; 40 CFR Part 600 Subpart B) shall be not greater than 1.33 times the applicable passenger car standards and 2.00 times the applicable light-duty truck standards shown in the table. Both the projected emissions and the HWFET standard shall be rounded in accordance with ASTM E29-67 to the nearest 0.1 g/mi before being compared.
- (4) Small volume manufacturers may choose to certify to an optional 0.7 g/mi NOx standard for the 1995 model year only, pursuant to the conditions set forth in Title 13, California Code of Regulations, Sections 1960.1(f)(1) and 1960.1.5.
- (5) Diesel passenger cars and light-duty trucks certifying to these standards are subject to a particulate exhaust emission standard of 0.08 g/mi, determined on a 50,000 mile durability vehicle basis.
- (6) For gaseous-fueled vehicles certifying to these standards, the calculation procedures provided in Appendix V shall be used for determining fuel economy.
- (7) For all vehicles, except those certifying to optional diesel standards, in-use compliance with the exhaust emission standards shall be limited to vehicles with less than 75,000 miles.
- (8) For the 1995 and 1996 model years, all manufacturers, except those certifying to optional diesel standards, are permitted alternative in-use compliance. Alternative in-use compliance is permitted for 60% of a manufacturer's vehicles in the 1995 model year and 20% of a manufacturer's vehicles in the

1996 model year. For the 1995 and 1996 model years, small volume manufacturers only are permitted alternative in-use compliance for 100% of the fleet. The percentages shall be applied to the manufacturers' total projected sales of California-certified passenger cars and light-duty trucks for the model year. "Alternative in-use compliance" shall consist of the following:

- a. For all passenger cars and those light-duty trucks from 0-3750 lbs., loaded vehicle weight, except those diesel vehicles certifying to optional 100,000 mile standards, in-use compliance standards shall be 0.32 g/mi non-methane hydrocarbon and 5.2 g/mi carbon monoxide for 50,000 miles.
 - b. For light-duty trucks from 3751-5750 lbs., loaded vehicle weight, except those diesel light-duty trucks certifying to optional 100,000 mile standards, in-use compliance standards shall be 0.41 g/mi non-methane hydrocarbon and 6.7 g/mi carbon monoxide for 50,000 miles.
 - c. In-use compliance standards shall be waived beyond 50,000 miles.
- (9) All passenger cars and light-duty trucks, except those diesel vehicles certifying to optional standards, are subject to non-methane hydrocarbon, carbon monoxide, and oxides of nitrogen standards determined on a 50,000 mile durability basis and non-methane hydrocarbon and carbon monoxide standards determined on a 100,000 mile durability basis.
- (10) All 1996 and subsequent model-year PCs and LDTs shall comply with the applicable 100,000 mile standards for NOx.
- (11) Each manufacturer shall certify PCs or LDTs to the exhaust emission standards of Sections 3.f. and 3.g. of these test procedures such that the manufacturer's fleet average NMOG values for California-certified PCs and LDTs from 0-3750 lbs. Loaded Vehicle Weight (or "LVW"), and LDTs from 3751-5750 lbs. LVW produced and delivered for sale in California are less than or equal to the requirement for the corresponding Model Year, Vehicle Type, and LVW Class in Section 3.h. of these test procedures.

g. The exhaust emissions from new 1992-2000 model-year LEV I transitional low-emission vehicles, low-emission vehicles and ultra-low-emission vehicles, and new 2003 and subsequent model-year zero-emission vehicles shall not exceed:

**LEV I EXHAUST MASS EMISSION STANDARDS
FOR TRANSITIONAL LOW-EMISSION VEHICLES, LOW-EMISSION VEHICLES,
ULTRA-LOW-EMISSION VEHICLES AND ZERO-EMISSION VEHICLES IN
PASSENGER CAR AND LIGHT-DUTY TRUCK VEHICLE CLASSES** ^{6,7,8,9,10}
["grams per mile" (or "g/mi")]

<i>Vehicle Type¹</i>	<i>Loaded Vehicle Weight (lbs)</i>	<i>Durability Vehicle Basis (mi)</i>	<i>Vehicle Emission Category²</i>	<i>Non-Methane Organic Gases^{3,4}</i>	<i>Carbon Monoxide</i>	<i>Oxides of Nitrogen⁵</i>
PC and 0.4	All	50,000	TLEV		0.125	3.4
LDT	0-3750		LEV	0.075	3.4	0.2
			ULEV	0.040	1.7	0.2
		100,000	TLEV	0.156	4.2	0.6
			LEV	0.090	4.2	0.3
			ULEV	0.055	2.1	0.3
LDT 0.7	3751-5750	50,000	TLEV		0.160	4.4
			LEV	0.100	4.4	0.4
			ULEV	0.050	2.2	0.4
		100,000	TLEV	0.200	5.5	0.9
			LEV	0.130	5.5	0.5
			ULEV	0.070	2.8	0.5

- (1) "PC" means passenger cars.
"LDT" means light-duty trucks.
"LVW" means loaded vehicle weight.
"Non-Methane Organic Gases" or "NMOG" means the total mass of oxygenated and non-oxygenated hydrocarbon emissions.
- (2) "TLEV" means transitional low-emission vehicle.
"LEV" means low-emission vehicle.
"ULEV" means ultra-low-emission vehicle.
- (3) **Compliance with NMOG Standard.** To demonstrate compliance with an NMOG standard, NMOG emissions shall be measured in accordance with the "California Non-Methane Organic Gas Test Procedures" adopted July 12, 1991 and as last amended June 24, 1996.
 - a. **Reactivity Adjustment.** For TLEVs, LEVs, and ULEVs certified to operate on a fuel other than conventional gasoline, including fuel-flexible and dual-fuel vehicles when certifying on a fuel other than gasoline, manufacturers shall multiply the exhaust NMOG certification levels by the applicable reactivity adjustment factor set forth in Section 13 of these test procedures, or established by the Executive Officer pursuant to Appendix VIII of these test procedures. In addition, natural gas vehicles certifying to TLEV, LEV or ULEV standards shall calculate a reactivity-adjusted methane exhaust emission value by multiplying the methane exhaust certification level by the applicable methane reactivity adjustment factor set forth in section 13 of these test procedures. The product of

the exhaust NMOG certification levels and the reactivity adjustment factor shall be compared with the exhaust NMOG mass emission standards established for the particular vehicle emission category and fuel to determine compliance. For natural gas vehicles, the reactivity-adjusted NMOG value shall be added to the reactivity-adjusted methane value and then compared to the exhaust NMOG mass emission standards established for the particular vehicle emission category to determine compliance.

b. **Fleet Average Requirement.** Each manufacturer shall certify PCs or LDTs to meet the exhaust mass emission standards for TLEVs, LEVs, ULEVs, or to the exhaust emission standards of Sections 3.b., 3.e., or 3.f. of these test procedures, or as Zero-Emission Vehicles, such that the manufacturer's fleet average NMOG values for California-certified PCs and LDTs from 0-3750 lbs. LVW, and LDTs from 3751-5750 lbs. LVW, produced and delivered for sale in California are less than or equal to the requirement for the corresponding Model Year, Vehicle Type, and LVW Class in Section 3.h. of these test procedures.

- (4) **NMOG Standards for Fuel-Flexible and Dual-Fuel Vehicles.** Fuel-flexible and dual-fuel PCs and LDTs from 0-5750 lbs. LVW shall be certified to exhaust mass emission standards for NMOG established for the operation of the vehicle on an available fuel other than gasoline, and gasoline as specified in Section 9.a.1. of these test procedures.

a. **Reactivity Adjustment.** For TLEVs, LEVs, and ULEVs, when certifying for operation on a fuel other than gasoline, manufacturers shall multiply the exhaust NMOG certification levels by the applicable reactivity adjustment factor. In addition to multiplying the exhaust NMOG certification levels by the applicable reactivity adjustment factor, the exhaust methane certification level for natural gas vehicles shall be multiplied by the applicable methane reactivity adjustment factor and the resulting value shall be added to the reactivity-adjusted NMOG value. The exhaust NMOG certification levels for fuel-flexible or dual-fuel vehicles when certifying on gasoline shall not be multiplied by a reactivity adjustment factor.

b. **Standards for Fuel-Flexible and Dual Fuel Vehicles Operating on Gasoline.** For PCs and LDTs from 0-5750 lbs. LVW, the applicable exhaust mass emission standard for NMOG when certifying the vehicle for operation on gasoline shall be:

Vehicle Type	Weight (LVW)	Emission Category	Durability Vehicle Basis (g/mi)	
			50,000 Mile	100,000 Mile
PCs, LDT	All, 0-3750	TLEV	0.25	0.31
		LEV	0.125	0.156
		ULEV	0.075	0.090
LDT	3751-5750	TLEV	0.32	0.40
		LEV	0.160	0.200
		ULEV	0.100	0.130

- (5) **Highway NOx Standard.** The maximum projected emissions of Oxides of Nitrogen (or "NOx") measured on the federal Highway Fuel Economy Test (HWFET; 40 CFR 600 Subpart B) shall not be greater than 1.33 times the applicable light-duty vehicle standards shown in the table. Both the projected emissions and the HWFET standard shall be rounded in accordance with ASTM E29-67 to the nearest 0.1 g/mi before being compared.
- (6) **Intermediate In-Use Compliance Standards.** The following standards are intermediate in-use compliance standards for 50,000 and 100,000 miles for PCs and LDTs from 0-5750 lbs. LVW, including fuel-flexible and dual-fuel vehicles when operating on an available fuel other than gasoline.

Intermediate in-use compliance standards shall apply to TLEVs through the 1995 model year as follows:

	NMOG (g/mi)
PCs and LDTs 0-3750 lbs. LVW	0.188
LDTs 3751 - 5750 lbs. LVW	0.238

In-use compliance with standards beyond 50,000 miles shall be waived through the 1995 model year for TLEVs, and through the 1998 model year for LEVs and ULEVs. For LEVs and ULEVs, the following intermediate in-use standards shall apply:

Vehicle Type	Durability Vehicle Basis	LEV (g/mi)			ULEV (g/mi)			
		Model Year	NMOG	NOx	Model Year	NMOG	CO	NOx
PCs, 0-3750 lb. LVW LDTs	50,000	through 1998	0.100	0.3	through 1998	0.058	2.6	0.3
	50,000	1999	0.100	0.3	1999-2002	0.055	2.1	0.3
	100,000	1999	0.125	0.4	1999-2002	0.075	3.4	0.4
3751-5750 lb. LVW LDTs	50,000	through 1998	0.128	0.5	through 1998	0.075	3.3	0.5
	50,000	1999	0.130	0.5	1999-2002	0.070	2.8	0.5
	100,000	1999	0.160	0.7	1999-2002	0.100	4.4	0.7

a. **Reactivity Adjustment.** For TLEVs, LEVs, and ULEVs designed to operate on a fuel other than conventional gasoline, including fuel-flexible and dual-fuel vehicles when operating on a fuel other than gasoline, exhaust NMOG emission results shall be multiplied by the applicable reactivity adjustment factor to determine compliance with intermediate in-use compliance standards for NMOG. In addition to multiplying the exhaust NMOG emission results by the applicable reactivity adjustment factor, the exhaust methane emission results for natural gas vehicles shall be multiplied by the applicable methane reactivity adjustment factor and the resulting value shall be added to the reactivity-adjusted NMOG value. Exhaust NMOG mass emissions from fuel-flexible or dual-fuel vehicles when operating on gasoline shall not be multiplied by a reactivity adjustment factor.

b. **Intermediate In-Use Standards for Fuel-Flexible and Dual-Fuel Vehicles Operating on Gasoline.** For fuel-flexible and dual-fuel PCs and LDTs from 0-5750 lbs. LVW, intermediate in-use compliance standards for NMOG emissions at 50,000 miles when the vehicle is operated on gasoline shall be:

Vehicle Type	Loaded Vehicle Weight (LVW)	Emission Category	Durability Vehicle Basis (g/mi) 50,000 mi
PCs, LDT	All, 0-3750	TLEV	0.32
		LEV	0.188
		ULEV	0.100
LDT	3751-5750	TLEV	0.41
		LEV	0.238
		ULEV	0.128

Intermediate in-use compliance standards shall apply to TLEVs through the 1995 model year, and to LEVs and ULEVs through the 1998 model year. In-use compliance with standards beyond 50,000 miles shall be waived through the 1995 model year for TLEVs, and through the 1998 model year for LEVs and ULEVs.

- (7) **Diesel Standards.** Manufacturers of diesel vehicles shall also certify to particulate standards at 100,000 miles. For all PCs and LDTs from 0-3750 lbs. LVW, the particulate standard is 0.08 g/mi, 0.08 g/mi, and 0.04 g/mi for TLEVs, LEVs, and ULEVs, respectively. For LDTs from 3751-5750 lbs. LVW, the particulate standard is 0.10 g/mi, 0.10 g/mi, and 0.05 g/mi for TLEVs, LEVs, and ULEVs, respectively. For diesel vehicles certifying to the standards set forth in section 3.g. of these test procedures, "NMOG" shall mean non-methane hydrocarbons.
- (8) **50°F Requirement.** Manufacturers shall demonstrate compliance with the above standards for NMOG, carbon monoxide and NO_x at 50° F, according to the procedure specified in Section 11k of these test procedures. Hybrid electric, natural gas, and diesel-fueled vehicles shall be exempt from 50° F test requirements.
- (9) **Limit on In-Use Testing.** In-use compliance testing shall be limited to vehicles with fewer than 75,000 miles.
- (10) **HEV Requirements.** Deterioration factors for hybrid electric vehicles shall be based on the emissions and mileage accumulation of the auxiliary power unit. For certification purposes only, Type A hybrid electric vehicles shall demonstrate compliance with 50,000 mile emission standards (using 50,000 mile deterioration factors), and demonstrating compliance with 100,000 mile emission standards shall not be required. For certification purposes only, Type B hybrid electric vehicles shall demonstrate compliance with 50,000 mile emission standards (using 50,000 mile deterioration factors) and 100,000 mile emission standards (using 75,000 mile deterioration factors). For certification purposes only, Type C hybrid electric vehicles shall demonstrate compliance with 50,000 mile emission standards (using 50,000 mile deterioration factors) and 100,000 mile emission standards (using 100,000 mile deterioration factors).

APPENDIX B

N₂O REAL-TIME EXPERIMENTS

Sequential ID	Date	Test Type	Vehicle ID	Test ID	Vehicle	Catalyst	FTIR data flag	Temperature data flag	A/F data flag	NO data flag
1	1/29/2004	EC	1002971	1010939	Toyota 4runner 1997	In-use	Y	Y		Y
2	2/23/2004	EC	1002971	1011084	Toyota 4runner 1997	Empty	Y	Y		Y
3	2/25/2004	EC	1002971		Toyota 4runner 1997	New	Y			
4	2/18/2004	MN2O	1002971	1011005	Toyota 4runner 1997	In-use	Y	Y		Y
5	2/4/2004	UC	1002971	1010940	Toyota 4runner 1997	In-use	Y	Y		Y
6	3/4/2004	EC	1002991	1011168	Nissan Pathfinder 2002	In-use	Y	Y		Y
7	3/1/2004	MN2O	1002991	1011103	Nissan Pathfinder 2002	In-use	Y	Y		Y
8	3/8/2004	UC	1002991	1011169	Nissan Pathfinder 2002	In-use	Y	Y		Y
9	3/1/2004	EC	1003003	1011116	Saturn SC1 1998	In-use	Y	Y		Y
10	3/10/2004	EC	1003003	1011224	Saturn SC1 1998	Empty	Y	Y		Y
11	3/18/2004	EC	1003003	1011259	Saturn SC1 1998	New	Y	Y		Y
12	3/4/2004	MN2O	1003003	1011118	Saturn SC1 1998	In-use	Y	Y		Y
13	3/3/2004	UC	1003003	1011117	Saturn SC1 1998	In-use	Y	Y		Y
14	3/11/2004	UC	1003003	1011205	Saturn SC1 1998	Empty		Y		Y
15	3/22/2004	EC	1003030	1011275	Chevy Silverado 1992	In-use	Y	Y		Y
16	4/13/2004	EC	1003030	1011389	Chevy Silverado 1992	Empty	Y	Y		Y
17	4/21/2004	EC	1003030	1011474	Chevy Silverado 1992	New	Y	Y		Y
18	4/6/2004	MN2O	1003030	1011276	Chevy Silverado 1992	In-use	Y	Y		Y
19	3/25/2004	UC	1003030	1011274	Chevy Silverado 1992	In-use	Y	Y		Y
20	4/14/2004	UC	1003030	1011390	Chevy Silverado 1992	Empty	Y	Y		Y
21	4/22/2004	UC	1003030	1011473	Chevy Silverado 1992	New	Y	Y		Y
22	4/1/2004	EC	1003035	1011313	Toyota Camry 1998	In-use	Y	Y		Y
23	4/13/2004	EC	1003035	1011444	Toyota Camry 1998	Empty	Y	Y		Y
24	4/21/2004	EC	1003035	1011493	Toyota Camry 1998	New	Y	Y		Y
25	4/7/2004	MN2O	1003035	1011406	Toyota Camry 1999	In-use	Y	Y		Y
26	4/5/2004	UC	1003035	1011314	Toyota Camry 1998	In-use	Y	Y		Y
27	4/14/2004	UC	1003035	1011445	Toyota Camry 1998	Empty	Y	Y		Y
28	4/27/2004	UC	1003035	1011476	Toyota Camry 1999	New		Y		Y
29	4/5/2004	EC	1003043	1011380	Honda Civic 1998	In-use	Y	Y		Y

Sequential ID	Date	Test Type	Vehicle ID	Test ID	Vehicle	Catalyst	FTIR data flag	Temperature data flag	A/F data flag	NO data flag
30	4/13/2004	EC	1003043	1011446	Honda Civic 1998	Empty	Y	Y		Y
31	4/19/2004	EC	1003043	1011467	Honda Civic 1998	New	Y	Y		Y
32	4/7/2004	MN2O	1003043	1011381	Honda Civic 1998	In-use	Y	Y		Y
33	4/6/2004	UC	1003043	1011382	Honda Civic 1998	In-use	Y	Y		Y
34	4/14/2004	UC	1003043	1011447	Honda Civic 1998	Empty	Y	Y		Y
35	4/27/2004	UC	1003043	1011522	Honda Civic 1998	New	Y	Y		Y
36	7/16/2003	EC	1002710	1010052	Ford Explorer 2002	In-use	Y			
37	7/11/2003	UC	1002710	1010075	Ford Explorer 2002	In-use	Y			
38	7/11/2003	EC	1002711	1010053	GMC Sonoma 1996	In-use	Y			
39	7/17/2003	EC	1002711	1010117	GMC Sonoma 1996	In-use	Y			
40	7/30/2003	EC	1002711	1010161	GMC Sonoma 1996	New	Y			
41	7/18/2003	EC	1002731	1010115	GM Sierra 1998	In-use	Y			
42	7/24/2003	UC	1002732	1010106	Hyundai Santa Fe 2001	In-use	Y			
43	8/1/2003	EC	1002770	1010188	Chrysler Towncountry 1996	In-use	Y			
44	9/5/2003	EC	1002791	1010250	Chevy Xtreme 2000	In-use			Y	
45	8/29/2003	UC	1002791	1010244	Chevy Xtreme 2000	In-use	Y			
46	8/29/2003	EC	1002792	1010251	Saturn SL1 1995	In-use	Y			
47	9/10/2003	EC	1002792	1010269	Saturn SL1 1995	In-use			Y	
48	9/11/2003	UC	1002792	1010270	Saturn SL1 1995	In-use			Y	
49	9/9/2003	EC	1002793	1010255	VW Fox 1989	In-use	Y			
50	9/19/2003	EC	1002793	1010304	VW Fox 1989	In-use	Y			
51	10/8/2003	EC	1002793	1010397	VW Fox 1989	In-use	Y			
52	9/10/2003	EC	1002794	1010259	Nissan Maxima 1993	In-use	Y		Y	
53	9/19/2003	UC	1002794	1010301	Nissan Maxima 1993	In-use			Y	
54	9/10/2003	EC	1002795	1010260	Honda Accord 1991	In-use	Y			
55	9/24/2003	EC	1002795	1010322	Honda Accord 1991	In-use	Y			
56	9/9/2003	UC	1002795	1010257	Honda Accord 1991	In-use	Y		Y	
57	9/11/2003	UC	1002795	1010275	Honda Accord 1991	In-use			Y	
58	9/19/2003	EC	1002816	1010296	Saturn SL2 1991	In-use	Y		Y	

Sequential ID	Date	Test Type	Vehicle ID	Test ID	Vehicle	Catalyst	FTIR data flag	Temperature data flag	A/F data flag	NO data flag
59	10/17/2003	EC	1002816	1010431	Saturn SL2 1991	In-use	Y			
60	11/4/2003	EC	1002816	1010548	Saturn SL2 1991	In-use	Y			
61	9/17/2003	UC	1002816	1010297	Saturn SL2 1991	In-use	Y			
62	9/24/2003	EC	1002817	1010325	Toyota Sienna 1999	In-use	Y		Y	
63	9/23/2003	UC	1002817	1010309	Toyota Sienna 1999	In-use	Y		Y	
64	9/30/2003	EC	1002820	1010361	Dodge Grand Caravan 1996	In-use	Y			
65	9/25/2003	UC	1002820	1010331	Dodge Grand Caravan 1996	In-use			Y	
66	10/3/2003	EC	1002838	1010373	Chevrolet Malibu 1998	In-use	Y			
67	10/8/2003	UC	1002841	1010396	Toyota Corolla 1996	In-use	Y			
68	10/15/2003	EC	1002842	1010423	Oldsmobile Supreme 1988	In-use	Y	Y		
69	10/10/2003	UC	1002842	1010400	Oldsmobile Supreme 1988	In-use	Y			
70	10/17/2003	EC	1002846	1010427	Nissan 280Z 1983	In-use	Y	Y		
71	10/31/2003	EC	1002847	1010487	Toyota Celica 1982	In-use		Y		
72	10/22/2003	UC	1002847	1010436	Toyota Celica 1982	In-use	Y			
73	10/30/2003	EC	1002848	1010474	Toyota Avalon 2002	In-use		Y		
74	10/23/2003	UC	1002848	1010454	Toyota Avalon 2002	In-use	Y			
75	11/5/2003	EC	1002861	1010525	VW Jetta 2000	In-use	Y	Y		
76	10/31/2003	UC	1002861	1010501	VW Jetta 2000	In-use		Y		
77	11/14/2003	EC	1002862	1010560	Toyota Corolla 2001	In-use		Y		
78	11/6/2003	UC	1002862	1010518	Toyota Corolla 2001	In-use		Y		
79	11/19/2003	EC	1002881	1010571	Toyota PickUp 1987	In-use		Y		
80	11/20/2003	UC	1002881	1010598	Toyota PickUp 1987	In-use		Y		
81	11/19/2003	EC	1002882	1010567	Ford Ranger 1995	In-use		Y		
82	11/13/2003	UC	1002882	1010558	Ford Ranger 1995	In-use		Y		
83	11/20/2003	EC	1002883	1010576	Ford F250 XL 1996	In-use	Y	Y		
84	12/4/2003	EC	1002883	1010611	Ford F250 XL 1996	In-use		Y		
85	11/19/2003	UC	1002883	1010570	Ford F250 XL 1996	In-use	Y	Y		
86	12/4/2003	UC	1002883	1010612	Ford F250 XL 1996	In-use		Y		
87	11/20/2003	EC	1002884	1010582	Camaro Z28 1996	In-use	Y			

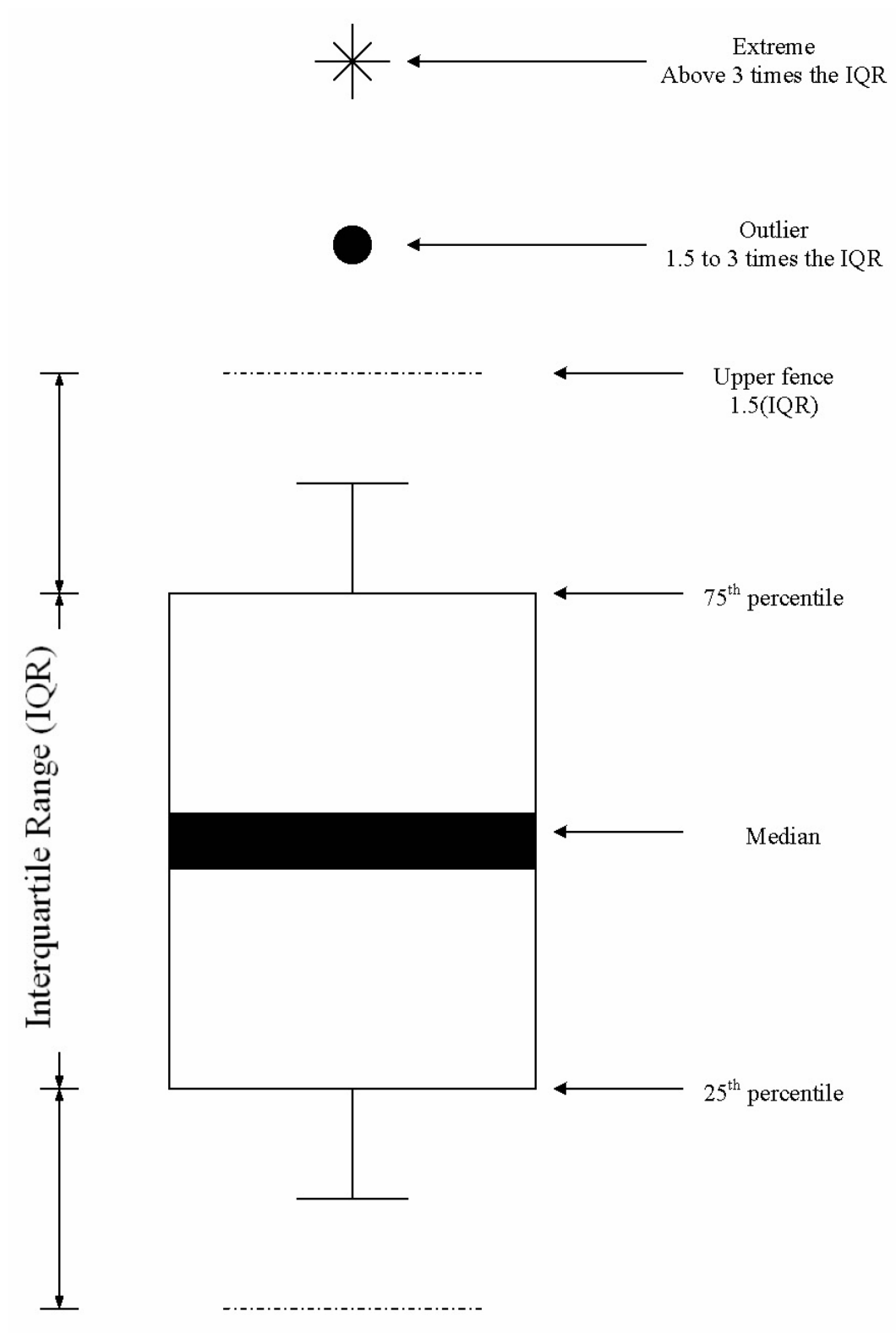
Sequential ID	Date	Test Type	Vehicle ID	Test ID	Vehicle	Catalyst	FTIR data flag	Temperature data flag	A/F data flag	NO data flag
88	11/19/2003	UC	1002884	1010577	Camaro Z28 1996	In-use		Y		
89	12/12/2003	EC	1002903	1010686	Ford Ranger 1995 (2)	In-use		Y		
90	12/16/2003	UC	1002903	1010667	Ford Ranger 1995 (2)	In-use		Y		
91	12/11/2003	EC	1002905	1010682	GMC Sierra 1998	In-use		Y		
92	12/10/2003	UC	1002905	1010674	GMC Sierra 1998	In-use	Y			
93	12/16/2003	UC	1002905	1010681	GMC Sierra 1998	In-use		Y		
94	12/17/2003	EC	1002907	1010687	Dodge RAM 1500 1998	In-use		Y		
95	12/18/2003	UC	1002907	1010684	Dodge RAM 1500 1998	In-use		Y		
96	12/17/2003	UC	1002927	1010706	Toyota Corolla 2000	In-use		Y		
97	12/19/2003	EC	1002928	1010731	Toyota Camry 1999	In-use		Y		
98	12/18/2003	UC	1002928	1010720	Toyota Camry 1999	In-use		Y		
99	1/13/2004	EC	1002931	1010787	Dodge Caravan 1997	In-use		Y		
100	1/15/2004	EC	1002952	1010819	Ford Explorer 2001	In-use		Y		
101	1/16/2004	EC	1002952	1010840	Ford Explorer 2001	In-use		Y		
102	1/14/2004	UC	1002952	1010807	Ford Explorer 2001	In-use		Y		
103	1/15/2004	EC	1002954	1010820	GM S-10 1995	In-use		Y		
104	1/21/2004	EC	1002954	1010860	GM S-10 1995	In-use		Y		
105	1/14/2004	UC	1002954	1010817	GM S-10 1995	In-use		Y		
106	1/22/2004	UC	1002954	1010861	GM S-10 1995	In-use		Y		
107	1/22/2004	EC	1002970	1010859	Ford Windstar 1995	In-use		Y		
108	1/28/2004	EC	1002970	1010887	Ford Windstar 1995	In-use		Y		Y
109	2/4/2004	EC	1002970	1010964	Ford Windstar 1995	In-use		Y		Y
110	1/21/2004	UC	1002970	1010842	Ford Windstar 1995	In-use		Y		
111	1/29/2004	UC	1002970	1010888	Ford Windstar 1995	In-use	Y	Y		
112	2/5/2004	UC	1002970	1010965	Ford Windstar 1995	In-use		Y		Y
113	1/22/2004	EC	1002971	1010868	Toyota 4runner 1997	In-use		Y		
114	1/27/2004	EC	1002971	1010880	Toyota 4runner 1997	In-use	Y	Y		
115	1/30/2004	EC	1002990	1010951	GM Tahoe 2001	In-use		Y		Y
116	1/29/2004	UC	1002990	1010919	GM Tahoe 2001	In-use		Y		Y

Sequential ID	Date	Test Type	Vehicle ID	Test ID	Vehicle	Catalyst	FTIR data flag	Temperature data flag	A/F data flag	NO data flag
117	2/4/2004	EC	1002992	1010963	Honda Civic CRX 1991	In-use	Y	Y		Y
118	1/30/2004	UC	1002992	1010943	Honda Civic CRX 1991	In-use		Y		Y
119	2/4/2004	EC	1002991	1010955	Nissan Pathfinder 2002	In-use	Y	Y		Y
120	1/30/2004	UC	1002991	1010944	Nissan Pathfinder 2002	In-use		Y		Y
121	2/5/2004	EC	1002994	1010967	Toyota Tacoma 1998	In-use	Y	Y		Y
122	2/4/2004	UC	1002994	1010958	Toyota Tacoma 1998	In-use	Y	Y		
123	2/5/2004	EC	1002997	1010983	BMW 318 1994	In-use				Y
124	2/4/2004	UC	1002997	1010970	BMW 318 1994	In-use	Y	Y		Y
125	2/6/2004	EC	1002995	1010984	Mercedes E320 2001	In-use		Y		Y
126	2/5/2004	UC	1002995	1010973	Mercedes E320 2001	In-use		Y		Y
127	2/24/2004	EC	1003001	1011029	Honda Accord 1989	In-use		Y		Y
128	3/3/2004	EC	1003001	1011114	Honda Accord 1989	In-use	Y	Y		Y
129	2/19/2004	UC	1003001	1011018	Honda Accord 1989	In-use		Y		Y
130	3/2/2004	UC	1003001	1011115	Honda Accord 1989	In-use		Y		Y
131	3/4/2004	UC	1003001	1011171	Honda Accord 1989	In-use		Y		
132	2/24/2004	EC	1003003	1011054	Saturn SC1 1998	In-use		Y		Y
133	2/19/2004	UC	1003003	1011045	Saturn SC1 1998	In-use	Y	Y		
134	2/24/2004	EC	1003006	1011059	Toyota PickUp 1994	In-use		Y		Y
135	3/30/2004	EC	1003006	1011349	Toyota PickUp 1994	In-use		Y		
136	2/19/2004	UC	1003006	1011055	Toyota PickUp 1994	In-use	Y	Y		Y
137	3/17/2004	UC	1003006	1011227	Toyota PickUp 1994	In-use		Y		
138	3/18/2004	UC	1003006	1011265	Toyota PickUp 1994	In-use		Y		
139	2/24/2004	EC	1003007	1011074	Honda Integra 1999	In-use		Y		Y
140	2/19/2004	UC	1003007	1011061	Honda Integra 1999	In-use	Y	Y		Y
141	2/25/2004	EC	1003022	1011113	GMC 1500 1996	In-use	Y	Y		Y
142	2/24/2004	UC	1003022	1011080	GMC 1500 1996	In-use		Y		Y
143	3/2/2004	UC	1003022	1011105	GMC 1500 1996	In-use		Y		Y
144	3/2/2004	EC	1003025	1011128	Honda Civic 2000	In-use		Y		Y
145	2/25/2004	UC	1003025	1011107	Honda Civic 2000	In-use		Y		

Sequential ID	Date	Test Type	Vehicle ID	Test ID	Vehicle	Catalyst	FTIR data flag	Temperature data flag	A/F data flag	NO data flag
146	3/2/2004	EC	1003026	1011138	Ford Ranger 1993	In-use		Y		Y
147	2/26/2004	UC	1003026	1011125	Ford Ranger 1993	In-use		Y		
148	3/4/2004	UC	1003026	1011148	Ford Ranger 1993	In-use		Y		
149	3/4/2004	EC	1003029	1011150	Ford Escort 1996	In-use		Y		Y
150	3/10/2004	EC	1003029	1011215	Ford Escort 1996	In-use		Y		Y
151	3/18/2004	EC	1003029	1011283	Ford Escort 1996	In-use		Y		
152	3/3/2004	UC	1003029	1011146	Ford Escort 1996	In-use		Y		Y
153	3/11/2004	UC	1003029	1011216	Ford Escort 1996	In-use		Y		Y
154	3/18/2004	EC	1003030	1011256	Chevy Silverado 1992	In-use		Y		
155	3/16/2004	EC	1003034	1011248	Chrysler Neon 1995	In-use		Y		Y
156	3/25/2004	EC	1003034	1011347	Chrysler Neon 1995	In-use		Y		Y
157	3/16/2004	EC	1003035	1011249	Toyota Camry 1998	In-use		Y		Y
158	3/24/2004	EC	1003035	1011296	Toyota Camry 1998	In-use		Y		Y
159	3/22/2004	UC	1003035	1011297	Toyota Camry 1998	In-use		Y		
160	3/25/2004	EC	1003043	1011323	Honda Civic 1998	In-use	Y	Y		Y
161	3/24/2004	UC	1003043	1011324	Honda Civic 1998	In-use		Y		Y

APPENDIX C

BOX PLOT SCHEMATIC AND DESCRIPTION



APPENDIX D

N₂O CONCENTRATIONS FROM INTEGRATED EXHAUST SAMPLES

Record	Date	Vehicle Test	Test ID	Phase/Bag	FTIR N₂O (ppm)	Proposed status
1	3/5/2003	1-EC-1	1009168	Background	0.35	DFR
1	3/5/2003	1-EC-1	1009168	Bag1	0.62	DFR
1	3/5/2003	1-EC-1	1009168	Bag2	0.32	DFR
1	3/5/2003	1-EC-1	1009168	Bag3	0.51	DFR
2	3/6/2003	2-EC-1	1009183	Background	0.35	DFR
2	3/6/2003	2-EC-1	1009183	Bag1	1.37	DFR
2	3/6/2003	2-EC-1	1009183	Bag2	0.44	DFR
2	3/6/2003	2-EC-1	1009183	Bag3	0.76	DFR
3	3/6/2003	1-UC-1	1009169	Background	0.34	DFR
3	3/6/2003	1-UC-1	1009169	Bag1	0.90	DFR
3	3/6/2003	1-UC-1	1009169	Bag2	0.38	DFR
3	3/6/2003	1-UC-1	1009169	Bag3	0.39	DFR
4	3/6/2003	1-M089-1	1009177	Background	0.34	DFR
4	3/6/2003	1-M089-1	1009177	Bag1	0.40	DFR
4	3/6/2003	1-M089-1	1009177	Bag2		N/A
4	3/6/2003	1-M089-1	1009177	Bag3		N/A
5	3/11/2003	2-UC-2	1009192	Background	0.33	DFR
5	3/11/2003	2-UC-2	1009192	Bag1	1.45	DFR
5	3/11/2003	2-UC-2	1009192	Bag2	0.63	DFR
5	3/11/2003	2-UC-2	1009192	Bag3	0.64	DFR
6	3/12/2003	3-EC-1	1009216	Background	0.33	DFR
6	3/12/2003	3-EC-1	1009216	Bag1	1.23	DFR
6	3/12/2003	3-EC-1	1009216	Bag2	0.41	DFR
6	3/12/2003	3-EC-1	1009216	Bag3	0.83	DFR
7	3/13/2003	4-EC-1	1009238	Background	0.32	DFR
7	3/13/2003	4-EC-1	1009238	Bag1	0.55	DFR
7	3/13/2003	4-EC-1	1009238	Bag2	0.32	DFR
7	3/13/2003	4-EC-1	1009238	Bag3	0.40	DFR
8	3/13/2003	3-UC-1	1009217	Background	0.32	DFR
8	3/13/2003	3-UC-1	1009217	Bag1	2.62	DFR
8	3/13/2003	3-UC-1	1009217	Bag2	0.92	DFR
8	3/13/2003	3-UC-1	1009217	Bag3	1.07	DFR
9	3/18/2003	4-UC-2	1009261	Background	0.35	DFR
9	3/18/2003	4-UC-2	1009261	Bag1	1.20	DFR
9	3/18/2003	4-UC-2	1009261	Bag2	0.38	DFR
9	3/18/2003	4-UC-2	1009261	Bag3	0.44	DFR
10	3/19/2003	5-EC-1	1009270	Background	0.33	DFR
10	3/19/2003	5-EC-1	1009270	Bag1	1.01	DFR
10	3/19/2003	5-EC-1	1009270	Bag2	0.40	DFR
10	3/19/2003	5-EC-1	1009270	Bag3	0.80	DFR
11	3/20/2003	6-EC-1	1009272	Background	0.32	DFR

Record	Date	Vehicle Test	Test ID	Phase/Bag	FTIR N₂O (ppm)	Proposed status
11	3/20/2003	6-EC-1	1009272	Bag1	0.79	DFR
11	3/20/2003	6-EC-1	1009272	Bag2	0.37	DFR
11	3/20/2003	6-EC-1	1009272	Bag3	0.52	DFR
12	3/20/2003	6-MO91-1	1009274	Background	0.33	DFR
12	3/20/2003	6-MO91-1	1009274	Bag1	0.45	Fail
12	3/20/2003	6-MO91-1	1009274	Bag2	0.42	Fail
12	3/20/2003	6-MO91-1	1009274	Bag3		N/A
13	3/21/2003	5-UC-1	1009271	Background	0.32	DFR
13	3/21/2003	5-UC-1	1009271	Bag1	1.79	DFR
13	3/21/2003	5-UC-1	1009271	Bag2	0.62	DFR
13	3/21/2003	5-UC-1	1009271	Bag3	0.73	DFR
14	3/21/2003	6-UC-1	1009275	Background	0.35	DFR
14	3/21/2003	6-UC-1	1009275	Bag1	0.94	DFR
14	3/21/2003	6-UC-1	1009275	Bag2	0.47	DFR
14	3/21/2003	6-UC-1	1009275	Bag3	0.51	FYI
15	3/21/2003	6-MO89-1	1009284	Background	0.33	DFR
15	3/21/2003	6-MO89-1	1009284	Bag1	0.45	DFR
15	3/21/2003	6-MO89-1	1009284	Bag2		N/A
15	3/21/2003	6-MO89-1	1009284	Bag3		N/A
16	3/26/2003	7-EC-1	1009296	Background	0.34	DFR
16	3/26/2003	7-EC-1	1009296	Bag1	1.69	DFR
16	3/26/2003	7-EC-1	1009296	Bag2	0.75	DFR
16	3/26/2003	7-EC-1	1009296	Bag3	1.99	DFR
17	3/27/2003	7-UC-1	1009297	Background	0.33	DFR
17	3/27/2003	7-UC-1	1009297	Bag1	2.60	DFR
17	3/27/2003	7-UC-1	1009297	Bag2	1.14	DFR
17	3/27/2003	7-UC-1	1009297	Bag3	2.36	DFR
18	3/27/2003	8-EC-1	1009331	Background	0.32	DFR
18	3/27/2003	8-EC-1	1009331	Bag1	1.66	DFR
18	3/27/2003	8-EC-1	1009331	Bag2	0.39	DFR
18	3/27/2003	8-EC-1	1009331	Bag3	1.27	DFR
19	3/28/2003	8-UC-1	1009333	Background	0.35	DFR
19	3/28/2003	8-UC-1	1009333	Bag1	2.36	DFR
19	3/28/2003	8-UC-1	1009333	Bag2	0.52	DFR
19	3/28/2003	8-UC-1	1009333	Bag3	1.08	DFR
20	4/3/2003	9-EC-1	1009341	Background	0.33	DFR
20	4/3/2003	9-EC-1	1009341	Bag1	2.46	DFR
20	4/3/2003	9-EC-1	1009341	Bag2	1.53	DFR
20	4/3/2003	9-EC-1	1009341	Bag3	4.65	DFR
21	4/4/2003	10-EC-1	1009349	Background	0.34	DFR
21	4/4/2003	10-EC-1	1009349	Bag1	0.75	DFR

Record	Date	Vehicle Test	Test ID	Phase/Bag	FTIR N₂O (ppm)	Proposed status
21	4/4/2003	10-EC-1	1009349	Bag2	0.32	DFR
21	4/4/2003	10-EC-1	1009349	Bag3	0.32	DFR
22	4/4/2003	10-MO91-1	1009348	Background	0.31	DFR
22	4/4/2003	10-MO91-1	1009348	Bag1	0.37	Fail
22	4/4/2003	10-MO91-1	1009348	Bag2	0.37	Fail
22	4/4/2003	10-MO91-1	1009348	Bag3		N/A
23	4/4/2003	9-UC-1	1009339	Background	0.33	Fail
23	4/4/2003	9-UC-1	1009339	Bag1	1.53	Fail
23	4/4/2003	9-UC-1	1009339	Bag2	3.13	Fail
23	4/4/2003	9-UC-1	1009339	Bag3	2.99	Fail
24	4/8/2003	10-UC-1	1009345	Background	0.34	DFR
24	4/8/2003	10-UC-1	1009345	Bag1	0.90	DFR
24	4/8/2003	10-UC-1	1009345	Bag2	0.35	DFR
24	4/8/2003	10-UC-1	1009345	Bag3	0.41	DFR
25	4/8/2003	10-MO89-1	1009357	Background	0.36	DFR
25	4/8/2003	10-MO89-1	1009357	Bag1	0.34	DFR
25	4/8/2003	10-MO89-1	1009357	Bag2		N/A
25	4/8/2003	10-MO89-1	1009357	Bag3		N/A
26	4/9/2003	11-EC-1	1009367	Background	0.33	DFR
26	4/9/2003	11-EC-1	1009367	Bag1	1.23	DFR
26	4/9/2003	11-EC-1	1009367	Bag2	0.39	DFR
26	4/9/2003	11-EC-1	1009367	Bag3	0.63	DFR
27	4/10/2003	12-UC-1	1009371	Background	0.31	DFR
27	4/10/2003	12-UC-1	1009371	Bag1	1.90	DFR
27	4/10/2003	12-UC-1	1009371	Bag2	0.39	DFR
27	4/10/2003	12-UC-1	1009371	Bag3	0.45	DFR
28	4/10/2003	10-MO91-1	1009374	Background	0.32	DFR
28	4/10/2003	10-MO91-1	1009374	Bag1	0.51	FYI
28	4/10/2003	10-MO91-1	1009374	Bag2	0.42	Fail
28	4/10/2003	10-MO91-1	1009374	Bag3		N/A
29	4/10/2003	9-UC-2	1009369	Background	0.32	DFR
29	4/10/2003	9-UC-2	1009369	Bag1	1.87	DFR
29	4/10/2003	9-UC-2	1009369	Bag2	1.96	DFR
29	4/10/2003	9-UC-2	1009369	Bag3	2.67	DFR
30	4/10/2003	11-UC-1	1009366	Background	0.31	DFR
30	4/10/2003	11-UC-1	1009366	Bag1	1.68	DFR
30	4/10/2003	11-UC-1	1009366	Bag2	0.50	DFR
30	4/10/2003	11-UC-1	1009366	Bag3	0.62	DFR
31	4/11/2003	13-UC-1	1009382	Background	0.32	DFR
31	4/11/2003	13-UC-1	1009382	Bag1	1.14	DFR
31	4/11/2003	13-UC-1	1009382	Bag2	0.36	DFR

Record	Date	Vehicle Test	Test ID	Phase/Bag	FTIR N ₂ O (ppm)	Proposed status
31	4/11/2003	13-UC-1	1009382	Bag3	0.40	DFR
32	4/11/2003	13-M091-1	1009385	Background	0.31	DFR
32	4/11/2003	13-M091-1	1009385	Bag1	0.36	Fail
32	4/11/2003	13-M091-1	1009385	Bag2	0.33	Fail
32	4/11/2003	13-M091-1	1009385	Bag3		N/A
33	4/15/2003	12-EC-1	1009386	Background	0.32	DFR
33	4/15/2003	12-EC-1	1009386	Bag1	1.27	DFR
33	4/15/2003	12-EC-1	1009386	Bag2	0.31	DFR
33	4/15/2003	12-EC-1	1009386	Bag3	1.09	DFR
34	4/15/2003	13-EC-1	1009395	Background	0.32	DFR
34	4/15/2003	13-EC-1	1009395	Bag1	0.70	DFR
34	4/15/2003	13-EC-1	1009395	Bag2	0.31	DFR
34	4/15/2003	13-EC-1	1009395	Bag3	0.35	DFR
35	4/15/2003	13-M089-1	1009389	Background	0.32	DFR
35	4/15/2003	13-M089-1	1009389	Bag1	0.35	DFR
35	4/15/2003	13-M089-1	1009389	Bag2		N/A
35	4/15/2003	13-M089-1	1009389	Bag3		N/A
36	4/16/2003	12-EC-2	1009397	Background	0.33	DFR
36	4/16/2003	12-EC-2	1009397	Bag1	1.10	DFR
36	4/16/2003	12-EC-2	1009397	Bag2	0.32	DFR
36	4/16/2003	12-EC-2	1009397	Bag3	0.50	DFR
37	4/17/2003	14-EC-1	1009413	Background	0.33	DFR
37	4/17/2003	14-EC-1	1009413	Bag1	1.82	DFR
37	4/17/2003	14-EC-1	1009413	Bag2	0.95	DFR
37	4/17/2003	14-EC-1	1009413	Bag3	2.49	DFR
38	4/17/2003	14-M091-1	1009406	Background	0.36	DFR
38	4/17/2003	14-M091-1	1009406	Bag1	1.53	DFR
38	4/17/2003	14-M091-1	1009406	Bag2	0.99	DFR
38	4/17/2003	14-M091-1	1009406	Bag3		N/A
39	4/17/2003	15-EC-1	1009414	Background	0.32	DFR
39	4/17/2003	15-EC-1	1009414	Bag1	1.05	DFR
39	4/17/2003	15-EC-1	1009414	Bag2	0.34	DFR
39	4/17/2003	15-EC-1	1009414	Bag3	0.34	DFR
40	4/17/2003	15-M091-1	1009412	Background	0.33	DFR
40	4/17/2003	15-M091-1	1009412	Bag1	1.01	DFR
40	4/17/2003	15-M091-1	1009412	Bag2	0.31	Fail
40	4/17/2003	15-M091-1	1009412	Bag3		N/A
41	4/18/2003	15-UC-1	1009409	Background	0.33	DFR
41	4/18/2003	15-UC-1	1009409	Bag1	1.19	DFR
41	4/18/2003	15-UC-1	1009409	Bag2	0.31	DFR
41	4/18/2003	15-UC-1	1009409	Bag3	0.32	DFR

Record	Date	Vehicle Test	Test ID	Phase/Bag	FTIR N₂O (ppm)	Proposed status
42	4/18/2003	15-M089-1	1009415	Background	0.34	DFR
42	4/18/2003	15-M089-1	1009415	Bag1	0.32	DFR
42	4/18/2003	15-M089-1	1009415	Bag2		N/A
42	4/18/2003	15-M089-1	1009415	Bag3		N/A
43	4/18/2003	14-UC-1	1009403	Background	0.33	DFR
43	4/18/2003	14-UC-1	1009403	Bag1	2.26	DFR
43	4/18/2003	14-UC-1	1009403	Bag2	1.08	DFR
43	4/18/2003	14-UC-1	1009403	Bag3	3.55	DFR
44	4/22/2003	14-M089-1	1009418	Background	0.33	DFR
44	4/22/2003	14-M089-1	1009418	Bag1	1.29	DFR
44	4/22/2003	14-M089-1	1009418	Bag2		N/A
44	4/22/2003	14-M089-1	1009418	Bag3		N/A
45	4/22/2003	16-UC-1	1009421	Background	0.32	DFR
45	4/22/2003	16-UC-1	1009421	Bag1	1.79	DFR
45	4/22/2003	16-UC-1	1009421	Bag2	1.10	DFR
45	4/22/2003	16-UC-1	1009421	Bag3	2.87	DFR
46	4/23/2003	16-EC-1	1009430	Background	0.33	DFR
46	4/23/2003	16-EC-1	1009430	Bag1	1.79	DFR
46	4/23/2003	16-EC-1	1009430	Bag2	0.72	DFR
46	4/23/2003	16-EC-1	1009430	Bag3	2.42	DFR
47	4/24/2003	17-EC-1	1009440	Background	0.33	DFR
47	4/24/2003	17-EC-1	1009440	Bag1	1.95	DFR
47	4/24/2003	17-EC-1	1009440	Bag2	1.04	DFR
47	4/24/2003	17-EC-1	1009440	Bag3	2.76	DFR
48	4/25/2003	17-UC-1	1009441	Background	0.34	DFR
48	4/25/2003	17-UC-1	1009441	Bag1	1.37	DFR
48	4/25/2003	17-UC-1	1009441	Bag2	1.24	DFR
48	4/25/2003	17-UC-1	1009441	Bag3	3.11	DFR
49	4/25/2003	19-UC-1	1009454	Background	0.33	DFR
49	4/25/2003	19-UC-1	1009454	Bag1	2.03	DFR
49	4/25/2003	19-UC-1	1009454	Bag2	1.37	DFR
49	4/25/2003	19-UC-1	1009454	Bag3	4.46	DFR
50	4/25/2003	20-UC-1	1009460	Background	0.34	DFR
50	4/25/2003	20-UC-1	1009460	Bag1	1.53	DFR
50	4/25/2003	20-UC-1	1009460	Bag2	0.82	DFR
50	4/25/2003	20-UC-1	1009460	Bag3	2.18	DFR
51	4/29/2003	19-EC-1	1009462	Background	0.34	DFR
51	4/29/2003	19-EC-1	1009462	Bag1	2.26	DFR
51	4/29/2003	19-EC-1	1009462	Bag2	0.83	DFR
51	4/29/2003	19-EC-1	1009462	Bag3	2.47	DFR
52	4/29/2003	18-EC-1	1009461	Background	0.33	DFR

Record	Date	Vehicle Test	Test ID	Phase/Bag	FTIR N₂O (ppm)	Proposed status
52	4/29/2003	18-EC-1	1009461	Bag1	0.54	Fail
52	4/29/2003	18-EC-1	1009461	Bag2	0.32	Fail
52	4/29/2003	18-EC-1	1009461	Bag3	0.37	Fail
53	4/29/2003	20-EC-1	1009463	Background	0.33	DFR
53	4/29/2003	20-EC-1	1009463	Bag1	1.24	DFR
53	4/29/2003	20-EC-1	1009463	Bag2	0.43	DFR
53	4/29/2003	20-EC-1	1009463	Bag3	1.69	DFR
54	4/30/2003	18-UC-1	1009451	Background	0.34	DFR
54	4/30/2003	18-UC-1	1009451	Bag1	0.52	DFR
54	4/30/2003	18-UC-1	1009451	Bag2	0.41	Fail
54	4/30/2003	18-UC-1	1009451	Bag3	0.39	DFR
55	5/2/2003	17-EC-2	1009527	Background	0.33	DFR
55	5/2/2003	17-EC-2	1009527	Bag1	1.56	DFR
55	5/2/2003	17-EC-2	1009527	Bag2	0.70	DFR
55	5/2/2003	17-EC-2	1009527	Bag3	2.52	DFR
56	5/2/2003	18-EC-2	1009526	Background	0.33	DFR
56	5/2/2003	18-EC-2	1009526	Bag1	0.51	Fail
56	5/2/2003	18-EC-2	1009526	Bag2	0.34	Fail
56	5/2/2003	18-EC-2	1009526	Bag3	0.44	FYI
57	5/6/2003	17-UC-2	1009543	Background	0.31	DFR
57	5/6/2003	17-UC-2	1009543	Bag1	0.97	DFR
57	5/6/2003	17-UC-2	1009543	Bag2	0.68	DFR
57	5/6/2003	17-UC-2	1009543	Bag3	2.26	DFR
58	5/6/2003	18-UC-2	1009531	Background	0.32	DFR
58	5/6/2003	18-UC-2	1009531	Bag1	0.42	Fail
58	5/6/2003	18-UC-2	1009531	Bag2	0.44	Fail
58	5/6/2003	18-UC-2	1009531	Bag3	0.37	Fail
59	5/7/2003	22-UC-1	1009559	Background	0.33	DFR
59	5/7/2003	22-UC-1	1009559	Bag1	1.00	Fail
59	5/7/2003	22-UC-1	1009559	Bag2	1.32	DFR
59	5/7/2003	22-UC-1	1009559	Bag3	1.21	DFR
60	5/7/2003	21-UC-1	1009545	Background	0.33	DFR
60	5/7/2003	21-UC-1	1009545	Bag1	0.41	DFR
60	5/7/2003	21-UC-1	1009545	Bag2	0.30	DFR
60	5/7/2003	21-UC-1	1009545	Bag3	0.39	DFR
61	5/7/2003	21-M089-1	1009562	Background	0.32	DFR
61	5/7/2003	21-M089-1	1009562	Bag1	0.29	DFR
61	5/7/2003	21-M089-1	1009562	Bag2		N/A
61	5/7/2003	21-M089-1	1009562	Bag3		N/A
62	5/8/2003	23-UC-1	1009584	Background	0.34	DFR
62	5/8/2003	23-UC-1	1009584	Bag1	0.96	DFR

Record	Date	Vehicle Test	Test ID	Phase/Bag	FTIR N₂O (ppm)	Proposed status
62	5/8/2003	23-UC-1	1009584	Bag2	0.43	DFR
62	5/8/2003	23-UC-1	1009584	Bag3	0.46	DFR
63	5/8/2003	22-EC-1	1009565	Background	0.33	DFR
63	5/8/2003	22-EC-1	1009565	Bag1	1.46	DFR
63	5/8/2003	22-EC-1	1009565	Bag2	1.21	DFR
63	5/8/2003	22-EC-1	1009565	Bag3	1.50	DFR
64	5/8/2003	23-M089-1	1009586	Background	0.33	DFR
64	5/8/2003	23-M089-1	1009586	Bag1	0.45	DFR
64	5/8/2003	23-M089-1	1009586	Bag2		N/A
64	5/8/2003	23-M089-1	1009586	Bag3		N/A
65	5/8/2003	21-M091-1	1009549	Background	0.35	DFR
65	5/8/2003	21-M091-1	1009549	Bag1	0.64	DFR
65	5/8/2003	21-M091-1	1009549	Bag2	0.42	DFR
65	5/8/2003	21-M091-1	1009549	Bag3		N/A
66	5/8/2003	21-EC-1	1009564	Background	0.33	DFR
66	5/8/2003	21-EC-1	1009564	Bag1	0.35	DFR
66	5/8/2003	21-EC-1	1009564	Bag2	0.31	DFR
66	5/8/2003	21-EC-1	1009564	Bag3	0.34	DFR
67	5/13/2003	21-EC-2	1009614	Background	0.33	DFR
67	5/13/2003	21-EC-2	1009614	Bag1	0.29	DFR
67	5/13/2003	21-EC-2	1009614	Bag2	0.29	DFR
67	5/13/2003	21-EC-2	1009614	Bag3	0.31	DFR
68	5/13/2003	23-EC-1	1009596	Background	0.32	DFR
68	5/13/2003	23-EC-1	1009596	Bag1	0.70	DFR
68	5/13/2003	23-EC-1	1009596	Bag2	0.36	DFR
68	5/13/2003	23-EC-1	1009596	Bag3	0.51	DFR
69	5/14/2003	23-UC-2	1009612	Background	0.33	DFR
69	5/14/2003	23-UC-2	1009612	Bag1	0.76	DFR
69	5/14/2003	23-UC-2	1009612	Bag2	0.41	DFR
69	5/14/2003	23-UC-2	1009612	Bag3		Aborted
70	5/14/2003	21-UC-2	1009615	Background	0.33	DFR
70	5/14/2003	21-UC-2	1009615	Bag1	0.67	DFR
70	5/14/2003	21-UC-2	1009615	Bag2	0.33	DFR
70	5/14/2003	21-UC-2	1009615	Bag3	0.39	DFR
71	5/15/2003	22-EC-2	1009625	Background	0.30	DFR
71	5/15/2003	22-EC-2	1009625	Bag1	0.61	Fail
71	5/15/2003	22-EC-2	1009625	Bag2	0.62	DFR
71	5/15/2003	22-EC-2	1009625	Bag3	0.79	DFR
72	5/16/2003	22-UC-2	1009626	Background	0.33	DFR
72	5/16/2003	22-UC-2	1009626	Bag1	0.47	Fail
72	5/16/2003	22-UC-2	1009626	Bag2	0.76	DFR

Record	Date	Vehicle Test	Test ID	Phase/Bag	FTIR N₂O (ppm)	Proposed status
72	5/16/2003	22-UC-2	1009626	Bag3	0.58	DFR
73	5/16/2003	25-UC-1	1009624	Background	0.31	DFR
73	5/16/2003	25-UC-1	1009624	Bag1	0.58	DFR
73	5/16/2003	25-UC-1	1009624	Bag2	0.55	DFR
73	5/16/2003	25-UC-1	1009624	Bag3	1.01	DFR
74	5/20/2003	25-EC-1	1009650	Background	0.32	DFR
74	5/20/2003	25-EC-1	1009650	Bag1	0.58	DFR
74	5/20/2003	25-EC-1	1009650	Bag2	0.42	DFR
74	5/20/2003	25-EC-1	1009650	Bag3	0.86	DFR
75	5/20/2003	26-UC-1	1009633	Background	0.32	DFR
75	5/20/2003	26-UC-1	1009633	Bag1	0.76	DFR
75	5/20/2003	26-UC-1	1009633	Bag2	0.30	DFR
75	5/20/2003	26-UC-1	1009633	Bag3	0.69	DFR
76	5/20/2003	26-M089-1	1009635	Background	0.33	DFR
76	5/20/2003	26-M089-1	1009635	Bag1	0.30	DFR
76	5/20/2003	26-M089-1	1009635	Bag2		N/A
76	5/20/2003	26-M089-1	1009635	Bag3		N/A
77	5/21/2003	22-EC-3	1009662	Background	0.34	DFR
77	5/21/2003	22-EC-3	1009662	Bag1	0.72	DFR
77	5/21/2003	22-EC-3	1009662	Bag2	0.68	DFR
77	5/21/2003	22-EC-3	1009662	Bag3	1.33	DFR
78	5/21/2003	26-M091-1	1009655	Background	0.32	DFR
78	5/21/2003	26-M091-1	1009655	Bag1	0.31	Fail
78	5/21/2003	26-M091-1	1009655	Bag2	0.30	Fail
78	5/21/2003	26-M091-1	1009655	Bag3		N/A
79	5/21/2003	27-UC-1	1009659	Background	0.33	DFR
79	5/21/2003	27-UC-1	1009659	Bag1	1.95	DFR
79	5/21/2003	27-UC-1	1009659	Bag2	0.62	DFR
79	5/21/2003	27-UC-1	1009659	Bag3	0.67	DFR
80	5/21/2003	26-EC-1	1009654	Background	0.33	DFR
80	5/21/2003	26-EC-1	1009654	Bag1	0.69	DFR
80	5/21/2003	26-EC-1	1009654	Bag2	0.29	DFR
80	5/21/2003	26-EC-1	1009654	Bag3	0.61	DFR
81	5/22/2003	27-EC-1	1009674	Background	0.32	DFR
81	5/22/2003	27-EC-1	1009674	Bag1	1.26	DFR
81	5/22/2003	27-EC-1	1009674	Bag2	0.31	DFR
81	5/22/2003	27-EC-1	1009674	Bag3	0.68	DFR
82	5/22/2003	24-UC-1	1009664	Background	0.36	DFR
82	5/22/2003	24-UC-1	1009664	Bag1	3.03	DFR
82	5/22/2003	24-UC-1	1009664	Bag2	5.18	DFR
82	5/22/2003	24-UC-1	1009664	Bag3	2.35	DFR

Record	Date	Vehicle Test	Test ID	Phase/Bag	FTIR N₂O (ppm)	Proposed status
83	5/23/2003	24-EC-1	1009673	Background	0.32	DFR
83	5/23/2003	24-EC-1	1009673	Bag1	7.12	DFR
83	5/23/2003	24-EC-1	1009673	Bag2	5.28	DFR
83	5/23/2003	24-EC-1	1009673	Bag3	3.65	DFR
84	5/28/2003	29-M089-1	1009693	Background	0.33	DFR
84	5/28/2003	29-M089-1	1009693	Bag1	0.33	DFR
84	5/28/2003	29-M089-1	1009693	Bag2		N/A
84	5/28/2003	29-M089-1	1009693	Bag3		N/A
85	5/28/2003	30-UC-1	1009698	Background	0.33	DFR
85	5/28/2003	30-UC-1	1009698	Bag1	2.66	DFR
85	5/28/2003	30-UC-1	1009698	Bag2	0.54	DFR
85	5/28/2003	30-UC-1	1009698	Bag3	1.25	DFR
86	5/29/2003	22-UC-3	1009663	Background	0.32	DFR
86	5/29/2003	22-UC-3	1009663	Bag1	0.54	Fail
86	5/29/2003	22-UC-3	1009663	Bag2	0.47	DFR
86	5/29/2003	22-UC-3	1009663	Bag3	0.87	DFR
87	5/29/2003	30-EC-1	1009714	Background	0.31	DFR
87	5/29/2003	30-EC-1	1009714	Bag1	1.51	DFR
87	5/29/2003	30-EC-1	1009714	Bag2	0.45	DFR
87	5/29/2003	30-EC-1	1009714	Bag3	1.11	DFR
88	5/29/2003	31-UC-1	1009721	Background	0.33	DFR
88	5/29/2003	31-UC-1	1009721	Bag1	1.50	DFR
88	5/29/2003	31-UC-1	1009721	Bag2	0.55	DFR
88	5/29/2003	31-UC-1	1009721	Bag3	0.69	DFR
89	5/29/2003	25-EC-2	1009711	Background	0.32	DFR
89	5/29/2003	25-EC-2	1009711	Bag1	0.58	DFR
89	5/29/2003	25-EC-2	1009711	Bag2	0.44	DFR
89	5/29/2003	25-EC-2	1009711	Bag3	0.86	DFR
90	5/29/2003	29-UC-1	1009691	Background	0.32	DFR
90	5/29/2003	29-UC-1	1009691	Bag1	0.69	DFR
90	5/29/2003	29-UC-1	1009691	Bag2	0.35	DFR
90	5/29/2003	29-UC-1	1009691	Bag3	0.40	DFR
91	5/30/2003	31-EC-1	1009732	Background	0.33	DFR
91	5/30/2003	31-EC-1	1009732	Bag1	0.81	DFR
91	5/30/2003	31-EC-1	1009732	Bag2	0.39	DFR
91	5/30/2003	31-EC-1	1009732	Bag3	0.80	DFR
92	5/30/2003	29-EC-1	1009713	Background	0.31	DFR
92	5/30/2003	29-EC-1	1009713	Bag1	0.60	DFR
92	5/30/2003	29-EC-1	1009713	Bag2	0.29	DFR
92	5/30/2003	29-EC-1	1009713	Bag3	0.33	DFR
93	5/30/2003	29-M091-1	1009716	Background	0.33	DFR

Record	Date	Vehicle Test	Test ID	Phase/Bag	FTIR N₂O (ppm)	Proposed status
93	5/30/2003	29-M091-1	1009716	Bag1	0.57	DFR
93	5/30/2003	29-M091-1	1009716	Bag2	0.45	Fail
93	5/30/2003	29-M091-1	1009716	Bag3		N/A
94	5/30/2003	25-UC-2	1009712	Background	0.33	DFR
94	5/30/2003	25-UC-2	1009712	Bag1	0.56	DFR
94	5/30/2003	25-UC-2	1009712	Bag2	0.58	DFR
94	5/30/2003	25-UC-2	1009712	Bag3	1.19	DFR
95	6/3/2003	28-UC-1	1009727	Background	0.32	DFR
95	6/3/2003	28-UC-1	1009727	Bag1	0.75	DFR
95	6/3/2003	28-UC-1	1009727	Bag2	0.29	DFR
95	6/3/2003	28-UC-1	1009727	Bag3	0.30	DFR
96	6/3/2003	28-M089-1	1009725	Background	0.32	DFR
96	6/3/2003	28-M089-1	1009725	Bag1	0.28	DFR
96	6/3/2003	28-M089-1	1009725	Bag2		N/A
96	6/3/2003	28-M089-1	1009725	Bag3		N/A
97	6/3/2003	32-UC-1	1009723	Background	0.33	DFR
97	6/3/2003	32-UC-1	1009723	Bag1	1.21	DFR
97	6/3/2003	32-UC-1	1009723	Bag2	0.56	DFR
97	6/3/2003	32-UC-1	1009723	Bag3	1.12	DFR
98	6/3/2003	33-UC-1	1009738	Background	0.32	DFR
98	6/3/2003	33-UC-1	1009738	Bag1	1.41	DFR
98	6/3/2003	33-UC-1	1009738	Bag2	0.49	DFR
98	6/3/2003	33-UC-1	1009738	Bag3	0.54	DFR
99	6/4/2003	28-EC-1	1009729	Background	0.33	DFR
99	6/4/2003	28-EC-1	1009729	Bag1	0.67	DFR
99	6/4/2003	28-EC-1	1009729	Bag2	0.30	DFR
99	6/4/2003	28-EC-1	1009729	Bag3	0.30	DFR
100	6/4/2003	28-M091-1	1002632	Background	0.32	DFR
100	6/4/2003	28-M091-1	1002632	Bag1	0.32	Fail
100	6/4/2003	28-M091-1	1002632	Bag2	0.32	Fail
100	6/4/2003	28-M091-1	1002632	Bag3		N/A
101	6/4/2003	32-EC-1	1009733	Background	0.33	DFR
101	6/4/2003	32-EC-1	1009733	Bag1	0.98	DFR
101	6/4/2003	32-EC-1	1009733	Bag2	0.49	DFR
101	6/4/2003	32-EC-1	1009733	Bag3	1.33	DFR
102	6/4/2003	33-EC-1	1009739	Background	0.32	DFR
102	6/4/2003	33-EC-1	1009739	Bag1	1.39	DFR
102	6/4/2003	33-EC-1	1009739	Bag2	0.33	DFR
102	6/4/2003	33-EC-1	1009739	Bag3	0.63	DFR
103	6/5/2003	34-UC-1	1009761	Background	0.33	DFR
103	6/5/2003	34-UC-1	1009761	Bag1	1.71	DFR

Record	Date	Vehicle Test	Test ID	Phase/Bag	FTIR N ₂ O (ppm)	Proposed status
103	6/5/2003	34-UC-1	1009761	Bag2	0.51	DFR
103	6/5/2003	34-UC-1	1009761	Bag3	1.43	DFR
104	6/5/2003	35-UC-1	1009763	Background	0.32	DFR
104	6/5/2003	35-UC-1	1009763	Bag1	1.22	DFR
104	6/5/2003	35-UC-1	1009763	Bag2	0.63	DFR
104	6/5/2003	35-UC-1	1009763	Bag3	2.32	DFR
105	6/5/2003	36-UC-1	1009772	Background	0.34	DFR
105	6/5/2003	36-UC-1	1009772	Bag1	0.95	DFR
105	6/5/2003	36-UC-1	1009772	Bag2	1.98	DFR
105	6/5/2003	36-UC-1	1009772	Bag3	1.22	FYI
106	6/6/2003	34-EC-1	1009775	Background	0.30	DFR
106	6/6/2003	34-EC-1	1009775	Bag1	1.52	DFR
106	6/6/2003	34-EC-1	1009775	Bag2	0.42	DFR
106	6/6/2003	34-EC-1	1009775	Bag3	1.10	DFR
107	6/6/2003	35-EC-1	1009776	Background	0.36	DFR
107	6/6/2003	35-EC-1	1009776	Bag1	0.86	DFR
107	6/6/2003	35-EC-1	1009776	Bag2	0.38	DFR
107	6/6/2003	35-EC-1	1009776	Bag3	1.18	DFR
108	6/6/2003	36-EC-1	1009785	Background	0.32	DFR
108	6/6/2003	36-EC-1	1009785	Bag1	1.15	DFR
108	6/6/2003	36-EC-1	1009785	Bag2	0.99	DFR
108	6/6/2003	36-EC-1	1009785	Bag3	1.83	DFR
109	6/6/2003	37-UC-1	1009768	Background	0.31	DFR
109	6/6/2003	37-UC-1	1009768	Bag1	1.43	DFR
109	6/6/2003	37-UC-1	1009768	Bag2	0.32	DFR
109	6/6/2003	37-UC-1	1009768	Bag3	0.45	DFR
110	6/10/2003	37-EC-1	1009786	Background	0.32	DFR
110	6/10/2003	37-EC-1	1009786	Bag1	0.99	DFR
110	6/10/2003	37-EC-1	1009786	Bag2	0.29	DFR
110	6/10/2003	37-EC-1	1009786	Bag3	0.39	DFR
111	6/12/2003	37-M091-1	1009788	Background	0.32	DFR
111	6/12/2003	37-M091-1	1009788	Bag1	0.29	Fail
111	6/12/2003	37-M091-1	1009788	Bag2	0.29	Fail
111	6/12/2003	37-M091-1	1009788	Bag3		N/A
112	6/12/2003	36-EC-2	1009827	Background	0.33	DFR
112	6/12/2003	36-EC-2	1009827	Bag1	1.05	DFR
112	6/12/2003	36-EC-2	1009827	Bag2	0.92	DFR
112	6/12/2003	36-EC-2	1009827	Bag3	1.59	DFR
113	6/17/2003	36-UC-2	1009828	Background	0.32	DFR
113	6/17/2003	36-UC-2	1009828	Bag1	1.25	DFR
113	6/17/2003	36-UC-2	1009828	Bag2	2.06	DFR

Record	Date	Vehicle Test	Test ID	Phase/Bag	FTIR N₂O (ppm)	Proposed status
113	6/17/2003	36-UC-2	1009828	Bag3	0.76	DFR
114	6/17/2003	37-M089-1	1009770	Background	0.32	DFR
114	6/17/2003	37-M089-1	1009770	Bag1	0.32	DFR
114	6/17/2003	37-M089-1	1009770	Bag2		N/A
114	6/17/2003	37-M089-1	1009770	Bag3		N/A
115	6/17/2003	38-EC-1	1009869	Background	0.33	DFR
115	6/17/2003	38-EC-1	1009869	Bag1	1.19	DFR
115	6/17/2003	38-EC-1	1009869	Bag2	0.44	DFR
115	6/17/2003	38-EC-1	1009869	Bag3	1.26	DFR
116	6/18/2003	38-UC-1	1009826	Background	0.30	DFR
116	6/18/2003	38-UC-1	1009826	Bag1	1.40	DFR
116	6/18/2003	38-UC-1	1009826	Bag2	0.41	DFR
116	6/18/2003	38-UC-1	1009826	Bag3	1.39	DFR
117	6/18/2003	39-UC-1	1009892	Background	0.31	DFR
117	6/18/2003	39-UC-1	1009892	Bag1	1.85	DFR
117	6/18/2003	39-UC-1	1009892	Bag2	0.58	DFR
117	6/18/2003	39-UC-1	1009892	Bag3	1.09	DFR
118	6/20/2003	39-EC-1	1009913	Background	0.30	DFR
118	6/20/2003	39-EC-1	1009913	Bag1	1.87	DFR
118	6/20/2003	39-EC-1	1009913	Bag2	0.42	DFR
118	6/20/2003	39-EC-1	1009913	Bag3	1.05	DFR
119	6/20/2003	40-UC-1	1009919	Background	0.30	DFR
119	6/20/2003	40-UC-1	1009919	Bag1	1.36	DFR
119	6/20/2003	40-UC-1	1009919	Bag2	0.45	DFR
119	6/20/2003	40-UC-1	1009919	Bag3	2.18	DFR
120	6/24/2003	40-EC-1	1009950	Background	0.34	DFR
120	6/24/2003	40-EC-1	1009950	Bag1	0.91	DFR
120	6/24/2003	40-EC-1	1009950	Bag2	0.31	DFR
120	6/24/2003	40-EC-1	1009950	Bag3	1.87	DFR
121	6/26/2003	39-UC-2	1009983	Background	0.31	DFR
121	6/26/2003	39-UC-2	1009983	Bag1	0.94	Fail
121	6/26/2003	39-UC-2	1009983	Bag2	0.49	DFR
121	6/26/2003	39-UC-2	1009983	Bag3	0.76	DFR
122	6/27/2003	39-EC-2	1009982	Background	0.32	DFR
122	6/27/2003	39-EC-2	1009982	Bag1	1.31	DFR
122	6/27/2003	39-EC-2	1009982	Bag2	0.37	DFR
122	6/27/2003	39-EC-2	1009982	Bag3	0.71	DFR
123	7/10/2003	42-UC-1	1010045	Background	0.35	FYI
123	7/10/2003	42-UC-1	1010045	Bag1	0.63	FYI
123	7/10/2003	42-UC-1	1010045	Bag2	0.84	FYI
123	7/10/2003	42-UC-1	1010045	Bag3	1.20	FYI

Record	Date	Vehicle Test	Test ID	Phase/Bag	FTIR N₂O (ppm)	Proposed status
124	7/11/2003	41-UC-1	1010075	Background	0.31	FYI
124	7/11/2003	41-UC-1	1010075	Bag1	0.61	FYI
124	7/11/2003	41-UC-1	1010075	Bag2	0.32	FYI
124	7/11/2003	41-UC-1	1010075	Bag3	0.30	FYI
125	7/16/2003	42-UC-2	1010073	Background	0.32	DFR
125	7/16/2003	42-UC-2	1010073	Bag1	0.60	DFR
125	7/16/2003	42-UC-2	1010073	Bag2	0.74	DFR
125	7/16/2003	42-UC-2	1010073	Bag3	0.86	DFR
126	7/17/2003	41-UC-2	1010118	Background	0.32	FYI
126	7/17/2003	41-UC-2	1010118	Bag1	0.50	DFR
126	7/17/2003	41-UC-2	1010118	Bag2	0.33	DFR
126	7/17/2003	41-UC-2	1010118	Bag3	0.32	DFR
127	7/17/2003	41-M089-2	1010120	Background	0.34	FYI
127	7/17/2003	41-M089-2	1010120	Bag1	0.32	DFR
127	7/17/2003	41-M089-2	1010120	Bag2		N/A
127	7/17/2003	41-M089-2	1010120	Bag3		N/A
128	7/17/2003	42-EC-2	1010117	Background	0.39	FYI
128	7/17/2003	42-EC-2	1010117	Bag1	1.08	DFR
128	7/17/2003	42-EC-2	1010117	Bag2	0.71	DFR
128	7/17/2003	42-EC-2	1010117	Bag3	1.27	DFR
129	7/17/2003	43-M089-1	1010084	Background	0.33	FYI
129	7/17/2003	43-M089-1	1010084	Bag1	0.38	DFR
129	7/17/2003	43-M089-1	1010084	Bag2		N/A
129	7/17/2003	43-M089-1	1010084	Bag3		N/A
130	7/17/2003	43-UC-1	1010082	Background	0.34	FYI
130	7/17/2003	43-UC-1	1010082	Bag1	0.80	DFR
130	7/17/2003	43-UC-1	1010082	Bag2	0.50	DFR
130	7/17/2003	43-UC-1	1010082	Bag3	0.46	DFR
131	7/18/2003	41-M091-1	1010049	Background	0.32	FYI
131	7/18/2003	41-M091-1	1010049	Bag1		N/A
131	7/18/2003	41-M091-1	1010049	Bag2	0.28	Fail
131	7/18/2003	41-M091-1	1010049	Bag3		N/A
132	7/18/2003	41-EC-2	1010119	Background	0.31	FYI
132	7/18/2003	41-EC-2	1010119	Bag1	0.51	DFR
132	7/18/2003	41-EC-2	1010119	Bag2	0.32	DFR
132	7/18/2003	41-EC-2	1010119	Bag3	0.30	DFR
133	7/18/2003	43-M091-1	1010091	Background	0.32	FYI
133	7/18/2003	43-M091-1	1010091	Bag1		N/A
133	7/18/2003	43-M091-1	1010091	Bag2	0.34	DFR
133	7/18/2003	43-M091-1	1010091	Bag3		N/A
134	7/18/2003	43-EC-1	1010115	Background	0.32	FYI

Record	Date	Vehicle Test	Test ID	Phase/Bag	FTIR N₂O (ppm)	Proposed status
134	7/18/2003	43-EC-1	1010115	Bag1	0.48	DFR
134	7/18/2003	43-EC-1	1010115	Bag2	0.36	DFR
134	7/18/2003	43-EC-1	1010115	Bag3	0.45	DFR
135	7/24/2003	44-M089-1	1010110	Background	0.30	DFR
135	7/24/2003	44-M089-1	1010110	Bag1	0.30	DFR
135	7/24/2003	44-M089-1	1010110	Bag2		N/A
135	7/24/2003	44-M089-1	1010110	Bag3		N/A
136	7/24/2003	44-M091-1	1010108	Background	0.30	DFR
136	7/24/2003	44-M091-1	1010108	Bag1	0.31	DFR
136	7/24/2003	44-M091-1	1010108	Bag2	0.31	DFR
136	7/24/2003	44-M091-1	1010108	Bag3		N/A
137	7/23/2003	44-EC-1	1010116	Background	0.33	FYI
137	7/23/2003	44-EC-1	1010116	Bag1	0.43	DFR
137	7/23/2003	44-EC-1	1010116	Bag2	0.35	DFR
137	7/23/2003	44-EC-1	1010116	Bag3	0.35	DFR
138	7/24/2003	44-UC-1	1010106	Background	0.29	DFR
138	7/24/2003	44-UC-1	1010106	Bag1	0.34	DFR
138	7/24/2003	44-UC-1	1010106	Bag2	0.29	DFR
138	7/24/2003	44-UC-1	1010106	Bag3	0.36	DFR
139	7/29/2003	45-EC-1	1010147	Background	0.32	DFR
139	7/29/2003	45-EC-1	1010147	Bag1	0.52	DFR
139	7/29/2003	45-EC-1	1010147	Bag2	0.32	DFR
139	7/29/2003	45-EC-1	1010147	Bag3	0.68	DFR
140	7/29/2003	45-UC-1	1010146	Background	0.33	DFR
140	7/29/2003	45-UC-1	1010146	Bag1	0.66	DFR
140	7/29/2003	45-UC-1	1010146	Bag2	0.44	DFR
140	7/29/2003	45-UC-1	1010146	Bag3	0.66	DFR
141	7/30/2003	42-EC-3	1010161	Background	0.31	DFR
141	7/30/2003	42-EC-3	1010161	Bag1	0.61	DFR
141	7/30/2003	42-EC-3	1010161	Bag2	0.34	DFR
141	7/30/2003	42-EC-3	1010161	Bag3	0.34	DFR
142	8/1/2003	42-UC-3	1010162	Background	0.30	DFR
142	8/1/2003	42-UC-3	1010162	Bag1	0.43	DFR
142	8/1/2003	42-UC-3	1010162	Bag2	0.31	DFR
142	8/1/2003	42-UC-3	1010162	Bag3	0.32	DFR
143	8/1/2003	46-EC-1	1010188	Background	0.30	DFR
143	8/1/2003	46-EC-1	1010188	Bag1	0.67	DFR
143	8/1/2003	46-EC-1	1010188	Bag2	0.36	DFR
143	8/1/2003	46-EC-1	1010188	Bag3	0.57	DFR
144	8/1/2003	47-EC-1	1010193	Background	0.30	DFR
144	8/1/2003	47-EC-1	1010193	Bag1	0.48	DFR

Record	Date	Vehicle Test	Test ID	Phase/Bag	FTIR N₂O (ppm)	Proposed status
144	8/1/2003	47-EC-1	1010193	Bag2	0.31	DFR
144	8/1/2003	47-EC-1	1010193	Bag3	0.36	DFR
145	8/5/2003	46-UC-1	1010189	Background	0.32	DFR
145	8/5/2003	46-UC-1	1010189	Bag1	0.84	DFR
145	8/5/2003	46-UC-1	1010189	Bag2	0.42	DFR
145	8/5/2003	46-UC-1	1010189	Bag3	0.73	DFR
146	8/5/2003	47-UC-1	1010191	Background	0.32	DFR
146	8/5/2003	47-UC-1	1010191	Bag1	0.69	DFR
146	8/5/2003	47-UC-1	1010191	Bag2	0.35	DFR
146	8/5/2003	47-UC-1	1010191	Bag3	0.40	DFR
147	8/28/2003	49-UC-1	1010246	Background	0.31	DFR
147	8/28/2003	49-UC-1	1010246	Bag1	0.77	DFR
147	8/28/2003	49-UC-1	1010246	Bag2	0.55	DFR
147	8/28/2003	49-UC-1	1010246	Bag3	0.75	DFR
148	8/29/2003	48-UC-1	1010244	Background	0.32	DFR
148	8/29/2003	48-UC-1	1010244	Bag1	0.44	DFR
148	8/29/2003	48-UC-1	1010244	Bag2	0.34	DFR
148	8/29/2003	48-UC-1	1010244	Bag3	0.55	DFR
149	8/29/2003	49-EC-1	1010251	Background	0.33	DFR
149	8/29/2003	49-EC-1	1010251	Bag1	0.71	DFR
149	8/29/2003	49-EC-1	1010251	Bag2	0.52	DFR
149	8/29/2003	49-EC-1	1010251	Bag3	0.91	DFR
150	8/29/2003	50-UC-1	1010248	Background	0.31	DFR
150	8/29/2003	50-UC-1	1010248	Bag1		N/A
150	8/29/2003	50-UC-1	1010248	Bag2	0.41	DFR
150	8/29/2003	50-UC-1	1010248	Bag3	0.51	DFR
151	9/9/2003	48-M091-1	1010265	Background	0.33	DFR
151	9/9/2003	48-M091-1	1010265	Bag1	0.36	DFR
151	9/9/2003	48-M091-1	1010265	Bag2	0.36	DFR
151	9/9/2003	48-M091-1	1010265	Bag3		N/A
152	9/9/2003	48-EC-1	1010250	Background	0.34	DFR
152	9/9/2003	48-EC-1	1010250	Bag1	0.42	DFR
152	9/9/2003	48-EC-1	1010250	Bag2	0.36	DFR
152	9/9/2003	48-EC-1	1010250	Bag3	0.43	DFR
153	9/9/2003	50-EC-1	1010255	Background	0.33	DFR
153	9/9/2003	50-EC-1	1010255	Bag1	0.45	DFR
153	9/9/2003	50-EC-1	1010255	Bag2	0.44	DFR
153	9/9/2003	50-EC-1	1010255	Bag3	0.73	DFR
154	9/9/2003	51-UC-1	1010254	Background	0.33	DFR
154	9/9/2003	51-UC-1	1010254	Bag1	1.44	DFR
154	9/9/2003	51-UC-1	1010254	Bag2	0.48	DFR

Record	Date	Vehicle Test	Test ID	Phase/Bag	FTIR N₂O (ppm)	Proposed status
154	9/9/2003	51-UC-1	1010254	Bag3	1.22	DFR
155	9/9/2003	52-UC-1	1010257	Background	0.33	DFR
155	9/9/2003	52-UC-1	1010257	Bag1	0.45	DFR
155	9/9/2003	52-UC-1	1010257	Bag2	0.40	DFR
155	9/9/2003	52-UC-1	1010257	Bag3	0.60	DFR
156	9/10/2003	48-M089-1	1010267	Background	0.31	DFR
156	9/10/2003	48-M089-1	1010267	Bag1	0.32	DFR
156	9/10/2003	48-M089-1	1010267	Bag2		N/A
156	9/10/2003	48-M089-1	1010267	Bag3		N/A
157	9/10/2003	49-EC-2	1010269	Background	0.32	DFR
157	9/10/2003	49-EC-2	1010269	Bag1	0.85	DFR
157	9/10/2003	49-EC-2	1010269	Bag2	0.53	DFR
157	9/10/2003	49-EC-2	1010269	Bag3	1.10	DFR
158	9/10/2003	51-EC-1	1010259	Background	0.31	DFR
158	9/10/2003	51-EC-1	1010259	Bag1	1.21	DFR
158	9/10/2003	51-EC-1	1010259	Bag2	0.42	DFR
158	9/10/2003	51-EC-1	1010259	Bag3	1.20	DFR
159	9/10/2003	52-EC-1	1010260	Background	0.31	DFR
159	9/10/2003	52-EC-1	1010260	Bag1	0.36	DFR
159	9/10/2003	52-EC-1	1010260	Bag2	0.36	DFR
159	9/10/2003	52-EC-1	1010260	Bag3	0.53	DFR
160	9/11/2003	49-UC-2	1010270	Background	0.32	DFR
160	9/11/2003	49-UC-2	1010270	Bag1	0.84	DFR
160	9/11/2003	49-UC-2	1010270	Bag2	0.58	DFR
160	9/11/2003	49-UC-2	1010270	Bag3	0.96	DFR
161	9/11/2003	52-UC-2	1010275	Background	0.31	DFR
161	9/11/2003	52-UC-2	1010275	Bag1	0.40	DFR
161	9/11/2003	52-UC-2	1010275	Bag2	0.40	DFR
161	9/11/2003	52-UC-2	1010275	Bag3	0.57	DFR
162	9/17/2003	51-EC-2	1010300	Background	0.32	DFR
162	9/17/2003	51-EC-2	1010300	Bag1	1.17	DFR
162	9/17/2003	51-EC-2	1010300	Bag2	0.43	DFR
162	9/17/2003	51-EC-2	1010300	Bag3	1.34	DFR
163	9/17/2003	53-UC-2	1010297	Background	0.32	DFR
163	9/17/2003	53-UC-2	1010297	Bag1	0.90	DFR
163	9/17/2003	53-UC-2	1010297	Bag2	0.72	DFR
163	9/17/2003	53-UC-2	1010297	Bag3	1.30	DFR
164	9/19/2003	51-UC-2	1010301	Background	0.33	DFR
164	9/19/2003	51-UC-2	1010301	Bag1	1.31	DFR
164	9/19/2003	51-UC-2	1010301	Bag2	0.57	DFR
164	9/19/2003	51-UC-2	1010301	Bag3	1.08	DFR

Record	Date	Vehicle Test	Test ID	Phase/Bag	FTIR N₂O (ppm)	Proposed status
165	9/19/2003	53-EC-1	1010296	Background	0.34	DFR
165	9/19/2003	53-EC-1	1010296	Bag1	0.83	DFR
165	9/19/2003	53-EC-1	1010296	Bag2	1.72	DFR
165	9/19/2003	53-EC-1	1010296	Bag3	1.11	DFR
166	9/23/2003	54-M089-1	1010314	Background	0.31	DFR
166	9/23/2003	54-M089-1	1010314	Bag1	0.55	DFR
166	9/23/2003	54-M089-1	1010314	Bag2		N/A
166	9/23/2003	54-M089-1	1010314	Bag3		N/A
167	9/23/2003	54-UC-1	1010309	Background	0.31	DFR
167	9/23/2003	54-UC-1	1010309	Bag1		N/A
167	9/23/2003	54-UC-1	1010309	Bag2	0.50	DFR
167	9/23/2003	54-UC-1	1010309	Bag3	0.94	DFR
168	9/24/2003	54-EC-1	1010325	Background	0.32	DFR
168	9/24/2003	54-EC-1	1010325	Bag1	0.71	DFR
168	9/24/2003	54-EC-1	1010325	Bag2	0.49	DFR
168	9/24/2003	54-EC-1	1010325	Bag3	0.86	DFR
169	9/25/2003	55-UC-1	1010331	Background	0.31	DFR
169	9/25/2003	55-UC-1	1010331	Bag1	0.57	DFR
169	9/25/2003	55-UC-1	1010331	Bag2	0.47	DFR
169	9/25/2003	55-UC-1	1010331	Bag3	0.59	DFR
170	9/30/2003	55-EC-1	1010361	Background	0.34	DFR
170	9/30/2003	55-EC-1	1010361	Bag1	0.59	DFR
170	9/30/2003	55-EC-1	1010361	Bag2	0.40	DFR
170	9/30/2003	55-EC-1	1010361	Bag3	0.62	DFR
171	10/1/2003	56-UC-1	1010365	Background	0.30	DFR
171	10/1/2003	56-UC-1	1010365	Bag1	1.25	DFR
171	10/1/2003	56-UC-1	1010365	Bag2	0.44	DFR
171	10/1/2003	56-UC-1	1010365	Bag3	0.39	DFR
172	10/1/2003	54-M091-1	1010312	Background	0.30	DFR
172	10/1/2003	54-M091-1	1010312	Bag1	0.55	DFR
172	10/1/2003	54-M091-1	1010312	Bag2	0.46	DFR
172	10/1/2003	54-M091-1	1010312	Bag3		N/A
173	10/3/2003	55-EC-2	1010383	Background	0.32	DFR
173	10/3/2003	55-EC-2	1010383	Bag1	0.58	DFR
173	10/3/2003	55-EC-2	1010383	Bag2	0.42	DFR
173	10/3/2003	55-EC-2	1010383	Bag3	0.64	DFR
174	10/3/2003	56-EC-1	1010373	Background	0.30	DFR
174	10/3/2003	56-EC-1	1010373	Bag1	0.91	DFR
174	10/3/2003	56-EC-1	1010373	Bag2	0.32	DFR
174	10/3/2003	56-EC-1	1010373	Bag3	0.45	DFR
175	10/3/2003	57-UC-1	1010376	Background	0.31	DFR

Record	Date	Vehicle Test	Test ID	Phase/Bag	FTIR N₂O (ppm)	Proposed status
175	10/3/2003	57-UC-1	1010376	Bag1	0.56	DFR
175	10/3/2003	57-UC-1	1010376	Bag2	0.35	DFR
175	10/3/2003	57-UC-1	1010376	Bag3	0.35	DFR
176	10/7/2003	55-UC-2	1010384	Background	0.33	DFR
176	10/7/2003	55-UC-2	1010384	Bag1	0.62	DFR
176	10/7/2003	55-UC-2	1010384	Bag2	0.47	DFR
176	10/7/2003	55-UC-2	1010384	Bag3	0.57	DFR
177	10/7/2003	57-EC-1	1010394	Background	0.32	DFR
177	10/7/2003	57-EC-1	1010394	Bag1	0.47	DFR
177	10/7/2003	57-EC-1	1010394	Bag2	0.34	DFR
177	10/7/2003	57-EC-1	1010394	Bag3	0.38	DFR
178	10/8/2003	57-M089-1	1010390	Background	0.31	DFR
178	10/8/2003	57-M089-1	1010390	Bag1	0.34	DFR
178	10/8/2003	57-M089-1	1010390	Bag2		N/A
178	10/8/2003	57-M089-1	1010390	Bag3		N/A
179	10/8/2003	58-UC-1	1010396	Background	0.32	DFR
179	10/8/2003	58-UC-1	1010396	Bag1	1.15	DFR
179	10/8/2003	58-UC-1	1010396	Bag2	0.41	DFR
179	10/8/2003	58-UC-1	1010396	Bag3	0.74	DFR
180	10/9/2003	54-M091-2	1010374	Background	0.31	DFR
180	10/9/2003	54-M091-2	1010374	Bag1	0.47	DFR
180	10/9/2003	54-M091-2	1010374	Bag2	0.43	DFR
180	10/9/2003	54-M091-2	1010374	Bag3		N/A
181	10/9/2003	58-EC-1	1010406	Background	0.29	DFR
181	10/9/2003	58-EC-1	1010406	Bag1	0.87	DFR
181	10/9/2003	58-EC-1	1010406	Bag2	0.40	DFR
181	10/9/2003	58-EC-1	1010406	Bag3	0.78	DFR
182	10/10/2003	59-UC-1	1010400	Background	0.32	DFR
182	10/10/2003	59-UC-1	1010400	Bag1	1.04	DFR
182	10/10/2003	59-UC-1	1010400	Bag2	0.63	DFR
182	10/10/2003	59-UC-1	1010400	Bag3	1.54	DFR
183	10/15/2003	59-EC-1	1010423	Background	0.33	DFR
183	10/15/2003	59-EC-1	1010423	Bag1	1.01	DFR
183	10/15/2003	59-EC-1	1010423	Bag2	0.37	DFR
183	10/15/2003	59-EC-1	1010423	Bag3	0.94	DFR
184	10/17/2003	59-EC-2	1010430	Background	0.33	DFR
184	10/17/2003	59-EC-2	1010430	Bag1	1.03	DFR
184	10/17/2003	59-EC-2	1010430	Bag2	0.38	DFR
184	10/17/2003	59-EC-2	1010430	Bag3	0.93	DFR
185	10/17/2003	53-EC-3	1010431	Background	0.33	DFR
185	10/17/2003	53-EC-3	1010431	Bag1	0.96	DFR

Record	Date	Vehicle Test	Test ID	Phase/Bag	FTIR N ₂ O (ppm)	Proposed status
185	10/17/2003	53-EC-3	1010431	Bag2	1.89	DFR
185	10/17/2003	53-EC-3	1010431	Bag3	1.16	DFR
186	10/17/2003	60-EC-1	1010427	Background	0.31	DFR
186	10/17/2003	60-EC-1	1010427	Bag1	0.51	DFR
186	10/17/2003	60-EC-1	1010427	Bag2	0.38	DFR
186	10/17/2003	60-EC-1	1010427	Bag3	0.54	DFR
187	10/17/2003	60-UC-1	1010425	Background	0.32	DFR
187	10/17/2003	60-UC-1	1010425	Bag1	0.49	DFR
187	10/17/2003	60-UC-1	1010425	Bag2	0.43	DFR
187	10/17/2003	60-UC-1	1010425	Bag3	0.63	DFR
188	10/23/2003	61-EC-1	1010445	Background	0.34	DFR
188	10/23/2003	61-EC-1	1010445	Bag1	0.40	DFR
188	10/23/2003	61-EC-1	1010445	Bag2	0.37	DFR
188	10/23/2003	61-EC-1	1010445	Bag3	0.41	DFR
189	10/23/2003	61-UC-1	1010436	Background	0.33	DFR
189	10/23/2003	61-UC-1	1010436	Bag1	0.41	DFR
189	10/23/2003	61-UC-1	1010436	Bag2	0.46	DFR
189	10/23/2003	61-UC-1	1010436	Bag3	0.39	DFR
190	10/23/2003	62-M091-1	1010455	Background	0.33	DFR
190	10/23/2003	62-M091-1	1010455	Bag1	0.48	DFR
190	10/23/2003	62-M091-1	1010455	Bag2	0.48	DFR
190	10/23/2003	62-M091-1	1010455	Bag3		N/A
191	10/23/2003	62-UC-1	1010454	Background	0.35	DFR
191	10/23/2003	62-UC-1	1010454	Bag1	0.83	DFR
191	10/23/2003	62-UC-1	1010454	Bag2	0.37	DFR
191	10/23/2003	62-UC-1	1010454	Bag3	0.61	DFR
192	10/29/2003	62-M091-2	1010482	Background	0.33	DFR
192	10/29/2003	62-M091-2	1010482	Bag1	0.43	DFR
192	10/29/2003	62-M091-2	1010482	Bag2	0.39	DFR
192	10/29/2003	62-M091-2	1010482	Bag3		N/A
193	10/29/2003	62-M089-1	1010476	Background	0.34	DFR
193	10/29/2003	62-M089-1	1010476	Bag1	0.37	DFR
193	10/29/2003	62-M089-1	1010476	Bag2		N/A
193	10/29/2003	62-M089-1	1010476	Bag3		N/A
194	10/30/2003	61-UC-2	1010486	Background	0.33	DFR
194	10/30/2003	61-UC-2	1010486	Bag1	0.41	DFR
194	10/30/2003	61-UC-2	1010486	Bag2	0.40	DFR
194	10/30/2003	61-UC-2	1010486	Bag3	0.41	DFR
195	10/30/2003	62-EC-1	1010474	Background	0.33	DFR
195	10/30/2003	62-EC-1	1010474	Bag1	0.58	DFR
195	10/30/2003	62-EC-1	1010474	Bag2	0.39	DFR

Record	Date	Vehicle Test	Test ID	Phase/Bag	FTIR N₂O (ppm)	Proposed status
195	10/30/2003	62-EC-1	1010474	Bag3	0.58	DFR
196	10/31/2003	61-EC-2	1010487	Background	0.33	DFR
196	10/31/2003	61-EC-2	1010487	Bag1	0.37	DFR
196	10/31/2003	61-EC-2	1010487	Bag2	0.34	DFR
196	10/31/2003	61-EC-2	1010487	Bag3	0.41	DFR
197	10/31/2003	63-UC-1	1010501	Background	0.32	DFR
197	10/31/2003	63-UC-1	1010501	Bag1	0.75	DFR
197	10/31/2003	63-UC-1	1010501	Bag2	0.33	DFR
197	10/31/2003	63-UC-1	1010501	Bag3	0.53	DFR
198	11/4/2003	62-UC-2	1010480	Background	0.33	DFR
198	11/4/2003	62-UC-2	1010480	Bag1	0.70	DFR
198	11/4/2003	62-UC-2	1010480	Bag2	0.36	DFR
198	11/4/2003	62-UC-2	1010480	Bag3	0.54	DFR
199	11/4/2003	63-M091-1	1010504	Background	0.33	DFR
199	11/4/2003	63-M091-1	1010504	Bag1	0.36	DFR
199	11/4/2003	63-M091-1	1010504	Bag2	0.35	DFR
199	11/4/2003	63-M091-1	1010504	Bag3		N/A
200	11/5/2003	63-EC-1	1010525	Background	0.33	DFR
200	11/5/2003	63-EC-1	1010525	Bag1	0.51	DFR
200	11/5/2003	63-EC-1	1010525	Bag2	0.32	DFR
200	11/5/2003	63-EC-1	1010525	Bag3	0.43	DFR
201	11/6/2003	64-M091-1	1010520	Background	0.35	DFR
201	11/6/2003	64-M091-1	1010520	Bag1	0.40	DFR
201	11/6/2003	64-M091-1	1010520	Bag2	0.38	DFR
201	11/6/2003	64-M091-1	1010520	Bag3		DFR
202	11/6/2003	64-UC-1	1010518	Background	0.35	DFR
202	11/6/2003	64-UC-1	1010518	Bag1	0.58	DFR
202	11/6/2003	64-UC-1	1010518	Bag2	0.36	DFR
202	11/6/2003	64-UC-1	1010518	Bag3	0.40	DFR
203	11/14/2003	64-EC-1	1010560	Background	0.33	Fail
203	11/14/2003	64-EC-1	1010560	Bag1	0.40	Fail
203	11/14/2003	64-EC-1	1010560	Bag2	0.33	Fail
203	11/14/2003	64-EC-1	1010560	Bag3	0.35	Fail
204	11/14/2003	65-UC-1	1010568	Background	0.36	DFR
204	11/14/2003	65-UC-1	1010568	Bag1	0.53	DFR
204	11/14/2003	65-UC-1	1010568	Bag2	0.50	DFR
204	11/14/2003	65-UC-1	1010568	Bag3	0.72	DFR
205	11/14/2003	66-UC-1	1010558	Background	0.33	DFR
205	11/14/2003	66-UC-1	1010558	Bag1	0.73	DFR
205	11/14/2003	66-UC-1	1010558	Bag2	0.54	DFR
205	11/14/2003	66-UC-1	1010558	Bag3	1.55	DFR

Record	Date	Vehicle Test	Test ID	Phase/Bag	FTIR N₂O (ppm)	Proposed status
206	11/19/2003	64-M089-1	1010591	Background	0.32	DFR
206	11/19/2003	64-M089-1	1010591	Bag1	0.34	DFR
206	11/19/2003	64-M089-1	1010591	Bag2		N/A
206	11/19/2003	64-M089-1	1010591	Bag3		N/A
207	11/19/2003	59-EC-7	1010575	Background	0.32	DFR
207	11/19/2003	59-EC-7	1010575	Bag1	0.71	DFR
207	11/19/2003	59-EC-7	1010575	Bag2	0.34	DFR
207	11/19/2003	59-EC-7	1010575	Bag3	0.43	DFR
208	11/19/2003	65-EC-1	1010571	Background	0.35	DFR
208	11/19/2003	65-EC-1	1010571	Bag1	0.53	DFR
208	11/19/2003	65-EC-1	1010571	Bag2	0.43	DFR
208	11/19/2003	65-EC-1	1010571	Bag3	0.58	DFR
209	11/19/2003	66-EC-1	1010567	Background	0.32	DFR
209	11/19/2003	66-EC-1	1010567	Bag1	0.73	DFR
209	11/19/2003	66-EC-1	1010567	Bag2	0.53	DFR
209	11/19/2003	66-EC-1	1010567	Bag3	1.01	DFR
210	11/19/2003	67-UC-1	1010570	Background	0.33	DFR
210	11/19/2003	67-UC-1	1010570	Bag1	1.61	DFR
210	11/19/2003	67-UC-1	1010570	Bag2	1.23	DFR
210	11/19/2003	67-UC-1	1010570	Bag3	2.96	DFR
211	11/19/2003	68-UC-1	1010577	Background	0.33	DFR
211	11/19/2003	68-UC-1	1010577	Bag1	0.65	DFR
211	11/19/2003	68-UC-1	1010577	Bag2	0.43	DFR
211	11/19/2003	68-UC-1	1010577	Bag3	0.44	DFR
212	11/20/2003	65-UC-1	1010598	Background	0.33	DFR
212	11/20/2003	65-UC-1	1010598	Bag1	0.54	DFR
212	11/20/2003	65-UC-1	1010598	Bag2	0.48	DFR
212	11/20/2003	65-UC-1	1010598	Bag3	0.66	DFR
213	11/20/2003	67-EC-1	1010576	Background	0.32	DFR
213	11/20/2003	67-EC-1	1010576	Bag1	2.17	DFR
213	11/20/2003	67-EC-1	1010576	Bag2	1.20	DFR
213	11/20/2003	67-EC-1	1010576	Bag3	2.13	DFR
214	11/20/2003	68-EC-1	1010582	Background	0.32	DFR
214	11/20/2003	68-EC-1	1010582	Bag1	0.48	DFR
214	11/20/2003	68-EC-1	1010582	Bag2	0.36	DFR
214	11/20/2003	68-EC-1	1010582	Bag3	0.43	DFR
215	11/21/2003	68-EC-2	1010608	Background	0.34	DFR
215	11/21/2003	68-EC-2	1010608	Bag1	0.48	DFR
215	11/21/2003	68-EC-2	1010608	Bag2	0.33	DFR
215	11/21/2003	68-EC-2	1010608	Bag3	0.42	DFR
216	12/4/2003	67-EC-2	1010611	Background	0.35	DFR

Record	Date	Vehicle Test	Test ID	Phase/Bag	FTIR N₂O (ppm)	Proposed status
216	12/4/2003	67-EC-2	1010611	Bag1	2.03	DFR
216	12/4/2003	67-EC-2	1010611	Bag2	1.17	DFR
216	12/4/2003	67-EC-2	1010611	Bag3	2.12	DFR
217	12/4/2003	67-UC-2	1010612	Background	0.33	DFR
217	12/4/2003	67-UC-2	1010612	Bag1	2.00	DFR
217	12/4/2003	67-UC-2	1010612	Bag2	0.96	DFR
217	12/4/2003	67-UC-2	1010612	Bag3	2.15	DFR
218	12/8/2003	65-EC-3	1010662	Background	0.34	DFR
218	12/8/2003	65-EC-3	1010662	Bag1	0.45	DFR
218	12/8/2003	65-EC-3	1010662	Bag2	0.36	DFR
218	12/8/2003	65-EC-3	1010662	Bag3	0.47	DFR
219	12/11/2003	70-EC-1	1010682	Background	0.34	DFR
219	12/11/2003	70-EC-1	1010682	Bag1	0.98	DFR
219	12/11/2003	70-EC-1	1010682	Bag2	0.55	DFR
219	12/11/2003	70-EC-1	1010682	Bag3	1.53	DFR
220	12/12/2003	69-EC-1	1010686	Background	0.34	DFR
220	12/12/2003	69-EC-1	1010686	Bag1	0.45	DFR
220	12/12/2003	69-EC-1	1010686	Bag2	0.39	DFR
220	12/12/2003	69-EC-1	1010686	Bag3	0.45	DFR
221	12/16/2003	69-UC-1	1010667	Background	0.35	DFR
221	12/16/2003	69-UC-1	1010667	Bag1	0.64	DFR
221	12/16/2003	69-UC-1	1010667	Bag2		N/A
221	12/16/2003	69-UC-1	1010667	Bag3	0.47	DFR
222	12/16/2003	70-UC-2	1010681	Background	0.37	DFR
222	12/16/2003	70-UC-2	1010681	Bag1	1.00	DFR
222	12/16/2003	70-UC-2	1010681	Bag2	0.66	DFR
222	12/16/2003	70-UC-2	1010681	Bag3	1.38	DFR
223	12/17/2003	71-EC-1	1010687	Background	0.36	DFR
223	12/17/2003	71-EC-1	1010687	Bag1	0.74	DFR
223	12/17/2003	71-EC-1	1010687	Bag2	0.45	DFR
223	12/17/2003	71-EC-1	1010687	Bag3	0.72	DFR
224	12/18/2003	72-EC-1	1010687	Background	0.37	DFR
224	12/18/2003	72-EC-1	1010687	Bag1	0.57	DFR
224	12/18/2003	72-EC-1	1010687	Bag2	0.38	DFR
224	12/18/2003	72-EC-1	1010687	Bag3	0.60	DFR
225	12/17/2003	72-UC-1	1010706	Background	0.35	DFR
225	12/17/2003	72-UC-1	1010706	Bag1	0.92	DFR
225	12/17/2003	72-UC-1	1010706	Bag2	0.42	DFR
225	12/17/2003	72-UC-1	1010706	Bag3	0.54	DFR
226	12/17/2003	72-M089-1	1010710	Background	0.36	DFR
226	12/17/2003	72-M089-1	1010710	Bag1	0.37	DFR

Record	Date	Vehicle Test	Test ID	Phase/Bag	FTIR N₂O (ppm)	Proposed status
226	12/17/2003	72-M089-1	1010710	Bag2		N/A
226	12/17/2003	72-M089-1	1010710	Bag3		N/A
227	12/18/2003	71-UC-1	1010684	Background	0.33	DFR
227	12/18/2003	71-UC-1	1010684	Bag1	0.96	DFR
227	12/18/2003	71-UC-1	1010684	Bag2	0.49	DFR
227	12/18/2003	71-UC-1	1010684	Bag3	0.57	DFR
228	12/18/2003	73-UC-1	1010720	Background	0.34	DFR
228	12/18/2003	73-UC-1	1010720	Bag1	1.04	DFR
228	12/18/2003	73-UC-1	1010720	Bag2	0.50	DFR
228	12/18/2003	73-UC-1	1010720	Bag3	0.99	DFR
229	12/19/2003	73-M089-1	1010724	Background	0.34	DFR
229	12/19/2003	73-M089-1	1010724	Bag1	0.54	DFR
229	12/19/2003	73-M089-1	1010724	Bag2		N/A
229	12/19/2003	73-M089-1	1010724	Bag3		N/A
230	12/19/2003	72-M091-1	1010708	Background	0.34	DFR
230	12/19/2003	72-M091-1	1010708	Bag1	0.44	DFR
230	12/19/2003	72-M091-1	1010708	Bag2	0.40	DFR
230	12/19/2003	72-M091-1	1010708	Bag3		N/A
231	12/19/2003	73-EC-1	1010731	Background	0.35	DFR
231	12/19/2003	73-EC-1	1010731	Bag1	1.00	DFR
231	12/19/2003	73-EC-1	1010731	Bag2	0.46	DFR
231	12/19/2003	73-EC-1	1010731	Bag3	0.92	DFR
232	12/23/2003	73-M091-2	1010742	Background	0.34	DFR
232	12/23/2003	73-M091-2	1010742	Bag1	0.43	DFR
232	12/23/2003	73-M091-2	1010742	Bag2	0.41	DFR
232	12/23/2003	73-M091-2	1010742	Bag3		N/A
233	12/30/2003	73-EC-2	1010755	Background	0.34	DFR
233	12/30/2003	73-EC-2	1010755	Bag1	0.98	DFR
233	12/30/2003	73-EC-2	1010755	Bag2	0.38	DFR
233	12/30/2003	73-EC-2	1010755	Bag3	0.66	DFR
234	12/31/2003	73-UC-2	1010756	Background	0.35	DFR
234	12/31/2003	73-UC-2	1010756	Bag1	0.99	DFR
234	12/31/2003	73-UC-2	1010756	Bag2	0.42	DFR
234	12/31/2003	73-UC-2	1010756	Bag3	0.73	DFR
235	1/8/2004	74-UC-1	1010773	Background	0.35	DFR
235	1/8/2004	74-UC-1	1010773	Bag1	1.46	DFR
235	1/8/2004	74-UC-1	1010773	Bag2	0.55	DFR
235	1/8/2004	74-UC-1	1010773	Bag3	1.23	DFR
236	1/9/2004	74-EC-1	1010786	Background	0.34	DFR
236	1/9/2004	74-EC-1	1010786	Bag1	1.22	DFR
236	1/9/2004	74-EC-1	1010786	Bag2	0.48	DFR

Record	Date	Vehicle Test	Test ID	Phase/Bag	FTIR N₂O (ppm)	Proposed status
236	1/9/2004	74-EC-1	1010786	Bag3	1.61	DFR
237	1/9/2004	75-UC-1	1010779	Background	0.35	DFR
237	1/9/2004	75-UC-1	1010779	Bag1	1.32	DFR
237	1/9/2004	75-UC-1	1010779	Bag2	0.47	DFR
237	1/9/2004	75-UC-1	1010779	Bag3	0.61	DFR
238	1/13/2004	75-EC-1	1010787	Background	0.35	DFR
238	1/13/2004	75-EC-1	1010787	Bag1	0.95	DFR
238	1/13/2004	75-EC-1	1010787	Bag2	0.38	DFR
238	1/13/2004	75-EC-1	1010787	Bag3	0.64	DFR
239	1/16/2004	76-M091-1	1010808	Background	0.33	DFR
239	1/16/2004	76-M091-1	1010808	Bag1	0.48	DFR
239	1/16/2004	76-M091-1	1010808	Bag2	0.40	DFR
239	1/16/2004	76-M091-1	1010808	Bag3		N/A
240	1/14/2004	76-UC-1	1010807	Background	0.34	DFR
240	1/14/2004	76-UC-1	1010807	Bag1	1.50	DFR
240	1/14/2004	76-UC-1	1010807	Bag2	0.38	DFR
240	1/14/2004	76-UC-1	1010807	Bag3	0.39	DFR
241	1/16/2004	76-EC-2	1010840	Background	0.32	DFR
241	1/16/2004	76-EC-2	1010840	Bag1	0.73	DFR
241	1/16/2004	76-EC-2	1010840	Bag2	0.33	DFR
241	1/16/2004	76-EC-2	1010840	Bag3	0.51	DFR
242	1/16/2004	76-M089-1	1010811	Background	0.33	DFR
242	1/16/2004	76-M089-1	1010811	Bag1	0.34	DFR
242	1/16/2004	76-M089-1	1010811	Bag2		N/A
242	1/16/2004	76-M089-1	1010811	Bag3		N/A
243	1/16/2004	77-EC-1	1010820	Background	0.33	DFR
243	1/16/2004	77-EC-1	1010820	Bag1	0.97	DFR
243	1/16/2004	77-EC-1	1010820	Bag2	0.51	DFR
243	1/16/2004	77-EC-1	1010820	Bag3	0.92	DFR
244	1/21/2004	77-EC-2	1010860	Background	0.35	DFR
244	1/21/2004	77-EC-2	1010860	Bag1	0.84	DFR
244	1/21/2004	77-EC-2	1010860	Bag2	0.46	DFR
244	1/21/2004	77-EC-2	1010860	Bag3	0.70	DFR
245	1/16/2004	77-UC-1	1010817	Background	0.33	DFR
245	1/16/2004	77-UC-1	1010817	Bag1	1.06	DFR
245	1/16/2004	77-UC-1	1010817	Bag2	0.64	DFR
245	1/16/2004	77-UC-1	1010817	Bag3	0.81	DFR
246	1/21/2004	78-UC-1	1010842	Background	0.35	DFR
246	1/21/2004	78-UC-1	1010842	Bag1	0.60	DFR
246	1/21/2004	78-UC-1	1010842	Bag2	0.43	DFR
246	1/21/2004	78-UC-1	1010842	Bag3	0.59	DFR

Record	Date	Vehicle Test	Test ID	Phase/Bag	FTIR N₂O (ppm)	Proposed status
247	1/21/2004	79-UC-1	1010848	Background	0.35	DFR
247	1/21/2004	79-UC-1	1010848	Bag1	1.05	DFR
247	1/21/2004	79-UC-1	1010848	Bag2	0.91	DFR
247	1/21/2004	79-UC-1	1010848	Bag3	1.35	DFR
248	1/22/2004	77-UC-2	1010861	Background	0.35	DFR
248	1/22/2004	77-UC-2	1010861	Bag1	1.04	DFR
248	1/22/2004	77-UC-2	1010861	Bag2	0.53	DFR
248	1/22/2004	77-UC-2	1010861	Bag3	0.61	DFR
249	1/22/2004	78-EC-1	1010859	Background	0.35	DFR
249	1/22/2004	78-EC-1	1010859	Bag1	0.51	DFR
249	1/22/2004	78-EC-1	1010859	Bag2	0.40	DFR
249	1/22/2004	78-EC-1	1010859	Bag3	0.54	DFR
250	1/22/2004	79-EC-1	1010868	Background	0.35	DFR
250	1/22/2004	79-EC-1	1010868	Bag1	1.19	DFR
250	1/22/2004	79-EC-1	1010868	Bag2	0.86	DFR
250	1/22/2004	79-EC-1	1010868	Bag3	1.65	DFR
251	1/29/2004	78-EC-2	1010887	Background	0.33	DFR
251	1/29/2004	78-EC-2	1010887	Bag1	0.45	DFR
251	1/29/2004	78-EC-2	1010887	Bag2	0.36	DFR
251	1/29/2004	78-EC-2	1010887	Bag3	0.46	DFR
252	1/29/2004	78-UC-2	1010888	Background	0.33	DFR
252	1/29/2004	78-UC-2	1010888	Bag1	0.50	DFR
252	1/29/2004	78-UC-2	1010888	Bag2	0.40	DFR
252	1/29/2004	78-UC-2	1010888	Bag3	0.54	DFR
253	1/29/2004	80-M089-1	1010923	Background	0.34	DFR
253	1/29/2004	80-M089-1	1010923	Bag1	0.37	DFR
253	1/29/2004	80-M089-1	1010923	Bag2		N/A
253	1/29/2004	80-M089-1	1010923	Bag3		N/A
254	1/29/2004	80-UC-1	1010919	Background	0.35	DFR
254	1/29/2004	80-UC-1	1010919	Bag1	0.90	DFR
254	1/29/2004	80-UC-1	1010919	Bag2	0.38	DFR
254	1/29/2004	80-UC-1	1010919	Bag3	0.42	DFR
255	1/30/2004	80-EC-1	1010951	Background	0.34	DFR
255	1/30/2004	80-EC-1	1010951	Bag1		N/A
255	1/30/2004	80-EC-1	1010951	Bag2	0.35	DFR
255	1/30/2004	80-EC-1	1010951	Bag3	0.49	DFR
256	1/30/2004	80-M091-1	1010921	Background	0.34	DFR
256	1/30/2004	80-M091-1	1010921	Bag1	0.42	DFR
256	1/30/2004	80-M091-1	1010921	Bag2	0.37	DFR
256	1/30/2004	80-M091-1	1010921	Bag3		N/A
257	1/30/2004	81-UC-1	1010943	Background	0.35	DFR

Record	Date	Vehicle Test	Test ID	Phase/Bag	FTIR N₂O (ppm)	Proposed status
257	1/30/2004	81-UC-1	1010943	Bag1	0.61	DFR
257	1/30/2004	81-UC-1	1010943	Bag2	0.68	DFR
257	1/30/2004	81-UC-1	1010943	Bag3	0.78	DFR
258	1/30/2004	82-UC-1	1010944	Background	0.34	DFR
258	1/30/2004	82-UC-1	1010944	Bag1	0.63	DFR
258	1/30/2004	82-UC-1	1010944	Bag2	0.39	DFR
258	1/30/2004	82-UC-1	1010944	Bag3	0.39	DFR
259	2/4/2004	82-M089-1	1010948	Background	0.34	DFR
259	2/4/2004	82-M089-1	1010948	Bag1	0.36	DFR
259	2/4/2004	82-M089-1	1010948	Bag2		N/A
259	2/4/2004	82-M089-1	1010948	Bag3		N/A
260	2/4/2004	82-M091-1	1010946	Background	0.33	DFR
260	2/4/2004	82-M091-1	1010946	Bag1	0.35	DFR
260	2/4/2004	82-M091-1	1010946	Bag2	0.33	DFR
260	2/4/2004	82-M091-1	1010946	Bag3		N/A
261	2/4/2004	81-EC-1	1010963	Background	0.33	DFR
261	2/4/2004	81-EC-1	1010963	Bag1	0.69	DFR
261	2/4/2004	81-EC-1	1010963	Bag2	0.50	DFR
261	2/4/2004	81-EC-1	1010963	Bag3	0.87	DFR
262	2/4/2004	82-EC-1	1010955	Background	0.33	DFR
262	2/4/2004	82-EC-1	1010955	Bag1	0.46	DFR
262	2/4/2004	82-EC-1	1010955	Bag2	0.35	DFR
262	2/4/2004	82-EC-1	1010955	Bag3	0.38	DFR
263	2/4/2004	83-UC-1	1010958	Background	0.34	DFR
263	2/4/2004	83-UC-1	1010958	Bag1	0.82	DFR
263	2/4/2004	83-UC-1	1010958	Bag2	0.36	DFR
263	2/4/2004	83-UC-1	1010958	Bag3	0.41	DFR
264	2/4/2004	84-UC-1	1010970	Background	0.34	DFR
264	2/4/2004	84-UC-1	1010970	Bag1	0.80	DFR
264	2/4/2004	84-UC-1	1010970	Bag2	0.41	DFR
264	2/4/2004	84-UC-1	1010970	Bag3	0.62	DFR
265	2/5/2004	83-EC-1	1010967	Background	0.34	DFR
265	2/5/2004	83-EC-1	1010967	Bag1	0.77	DFR
265	2/5/2004	83-EC-1	1010967	Bag2	0.34	DFR
265	2/5/2004	83-EC-1	1010967	Bag3	0.39	DFR
266	2/5/2004	84-EC-1	1010983	Background	0.34	DFR
266	2/5/2004	84-EC-1	1010983	Bag1	0.58	DFR
266	2/5/2004	84-EC-1	1010983	Bag2	0.37	DFR
266	2/5/2004	84-EC-1	1010983	Bag3	0.65	DFR
267	2/5/2004	85-M089-1	1010977	Background	0.33	DFR
267	2/5/2004	85-M089-1	1010977	Bag1	0.33	DFR

Record	Date	Vehicle Test	Test ID	Phase/Bag	FTIR N₂O (ppm)	Proposed status
267	2/5/2004	85-M089-1	1010977	Bag2		N/A
267	2/5/2004	85-M089-1	1010977	Bag3		N/A
268	2/5/2004	85-M091-1	1010975	Background	0.33	DFR
268	2/5/2004	85-M091-1	1010975	Bag1	0.33	DFR
268	2/5/2004	85-M091-1	1010975	Bag2	0.34	DFR
268	2/5/2004	85-M091-1	1010975	Bag3		N/A
269	2/5/2004	85-UC-1	1010973	Background	0.34	DFR
269	2/5/2004	85-UC-1	1010973	Bag1	0.35	DFR
269	2/5/2004	85-UC-1	1010973	Bag2	0.33	DFR
269	2/5/2004	85-UC-1	1010973	Bag3	0.33	DFR
270	2/6/2004	85-EC-1	1010984	Background	0.34	DFR
270	2/6/2004	85-EC-1	1010984	Bag1	0.34	DFR
270	2/6/2004	85-EC-1	1010984	Bag2	0.34	DFR
270	2/6/2004	85-EC-1	1010984	Bag3	0.38	DFR
271	2/11/2004	81-EC-2	1011006	Background	0.36	DFR
271	2/11/2004	81-EC-2	1011006	Bag1	0.75	DFR
271	2/11/2004	81-EC-2	1011006	Bag2	0.55	DFR
271	2/11/2004	81-EC-2	1011006	Bag3	0.91	DFR
272	2/19/2004	86-UC-1	1011018	Background	0.32	DFR
272	2/19/2004	86-UC-1	1011018	Bag1	1.01	DFR
272	2/19/2004	86-UC-1	1011018	Bag2	0.68	DFR
272	2/19/2004	86-UC-1	1011018	Bag3	1.10	DFR
273	2/19/2004	87-UC-1	1011045	Background	0.32	DFR
273	2/19/2004	87-UC-1	1011045	Bag1	0.51	FYI
273	2/19/2004	87-UC-1	1011045	Bag2	0.42	DFR
273	2/19/2004	87-UC-1	1011045	Bag3	0.72	DFR
274	2/19/2004	88-UC-1	1011055	Background	0.31	DFR
274	2/19/2004	88-UC-1	1011055	Bag1		N/A
274	2/19/2004	88-UC-1	1011055	Bag2	0.40	DFR
274	2/19/2004	88-UC-1	1011055	Bag3	0.57	DFR
275	2/19/2004	89-UC-1	1011061	Background	0.32	DFR
275	2/19/2004	89-UC-1	1011061	Bag1	0.94	DFR
275	2/19/2004	89-UC-1	1011061	Bag2	0.38	DFR
275	2/19/2004	89-UC-1	1011061	Bag3	0.45	DFR
276	2/25/2004	79-EC-2	1010880	Background	0.34	DFR
276	2/25/2004	79-EC-2	1010880	Bag1	0.92	DFR
276	2/25/2004	79-EC-2	1010880	Bag2	0.34	DFR
276	2/25/2004	79-EC-2	1010880	Bag3	0.52	DFR
277	2/25/2004	90-EC-1	1011113	Background	0.34	DFR
277	2/25/2004	90-EC-1	1011113	Bag1	0.77	DFR
277	2/25/2004	90-EC-1	1011113	Bag2	0.36	DFR

Record	Date	Vehicle Test	Test ID	Phase/Bag	FTIR N₂O (ppm)	Proposed status
277	2/25/2004	90-EC-1	1011113	Bag3	0.68	DFR
278	2/25/2004	86-EC-1	1011029	Background	0.35	DFR
278	2/25/2004	86-EC-1	1011029	Bag1	0.82	DFR
278	2/25/2004	86-EC-1	1011029	Bag2	0.52	DFR
278	2/25/2004	86-EC-1	1011029	Bag3	1.15	DFR
279	2/25/2004	87-EC-1	1011054	Background	0.34	DFR
279	2/25/2004	87-EC-1	1011054	Bag1	0.66	DFR
279	2/25/2004	87-EC-1	1011054	Bag2	0.37	DFR
279	2/25/2004	87-EC-1	1011054	Bag3	0.75	DFR
280	2/25/2004	88-EC-1	1011059	Background	0.35	DFR
280	2/25/2004	88-EC-1	1011059	Bag1	0.72	DFR
280	2/25/2004	88-EC-1	1011059	Bag2	0.50	DFR
280	2/25/2004	88-EC-1	1011059	Bag3	0.72	DFR
281	2/25/2004	89-EC-1	1011074	Background	0.34	DFR
281	2/25/2004	89-EC-1	1011074	Bag1	0.95	DFR
281	2/25/2004	89-EC-1	1011074	Bag2	0.36	DFR
281	2/25/2004	89-EC-1	1011074	Bag3	0.45	DFR
282	2/25/2004	90-UC-1	1011080	Background	0.36	DFR
282	2/25/2004	90-UC-1	1011080	Bag1		N/A
282	2/25/2004	90-UC-1	1011080	Bag2	0.42	DFR
282	2/25/2004	90-UC-1	1011080	Bag3	0.77	DFR
283	2/25/2004	91-UC-1	1011107	Background	0.34	DFR
283	2/25/2004	91-UC-1	1011107	Bag1	0.44	DFR
283	2/25/2004	91-UC-1	1011107	Bag2	0.37	DFR
283	2/25/2004	91-UC-1	1011107	Bag3	0.36	DFR
284	3/3/2004	86-EC-2	1011114	Background	0.34	DFR
284	3/3/2004	86-EC-2	1011114	Bag1	0.88	DFR
284	3/3/2004	86-EC-2	1011114	Bag2	0.41	DFR
284	3/3/2004	86-EC-2	1011114	Bag3	0.73	DFR
285	3/3/2004	86-UC-2	1011115	Background	0.34	DFR
285	3/3/2004	86-UC-2	1011115	Bag1		N/A
285	3/3/2004	86-UC-2	1011115	Bag2	0.49	DFR
285	3/3/2004	86-UC-2	1011115	Bag3	0.73	DFR
286	3/3/2004	90-UC-2	1011105	Background	0.34	DFR
286	3/3/2004	90-UC-2	1011105	Bag1	0.84	DFR
286	3/3/2004	90-UC-2	1011105	Bag2	0.43	DFR
286	3/3/2004	90-UC-2	1011105	Bag3	0.82	DFR
287	3/3/2004	91-M089-1	1011111	Background	0.33	DFR
287	3/3/2004	91-M089-1	1011111	Bag1	0.34	DFR
287	3/3/2004	91-M089-1	1011111	Bag2		N/A
287	3/3/2004	91-M089-1	1011111	Bag3		N/A

Record	Date	Vehicle Test	Test ID	Phase/Bag	FTIR N₂O (ppm)	Proposed status
288	3/3/2004	91-M091-1	1011109	Background	0.34	DFR
288	3/3/2004	91-M091-1	1011109	Bag1	0.38	DFR
288	3/3/2004	91-M091-1	1011109	Bag2	0.37	DFR
288	3/3/2004	91-M091-1	1011109	Bag3		N/A
289	3/3/2004	91-EC-1	1011128	Background	0.34	DFR
289	3/3/2004	91-EC-1	1011128	Bag1	0.41	DFR
289	3/3/2004	91-EC-1	1011128	Bag2	0.34	DFR
289	3/3/2004	91-EC-1	1011128	Bag3	0.34	DFR
290	3/3/2004	92-EC-1	1011138	Background	0.34	DFR
290	3/3/2004	92-EC-1	1011138	Bag1	0.57	DFR
290	3/3/2004	92-EC-1	1011138	Bag2	0.39	DFR
290	3/3/2004	92-EC-1	1011138	Bag3	0.77	DFR
291	3/3/2004	93-UC-1	1011146	Background	0.34	DFR
291	3/3/2004	93-UC-1	1011146	Bag1	0.78	DFR
291	3/3/2004	93-UC-1	1011146	Bag2	0.39	DFR
291	3/3/2004	93-UC-1	1011146	Bag3	0.52	DFR
292	3/4/2004	86-UC-3	1011171	Background	0.32	DFR
292	3/4/2004	86-UC-3	1011171	Bag1	0.70	DFR
292	3/4/2004	86-UC-3	1011171	Bag2	0.50	DFR
292	3/4/2004	86-UC-3	1011171	Bag3	0.66	DFR
293	3/4/2004	93-EC-1	1011150	Background	0.32	DFR
293	3/4/2004	93-EC-1	1011150	Bag1	0.59	DFR
293	3/4/2004	93-EC-1	1011150	Bag2	0.35	DFR
293	3/4/2004	93-EC-1	1011150	Bag3	0.43	DFR
294	3/10/2004	88-UC-3	1011182	Background	0.33	DFR
294	3/10/2004	88-UC-3	1011182	Bag1	0.70	DFR
294	3/10/2004	88-UC-3	1011182	Bag2	0.45	DFR
294	3/10/2004	88-UC-3	1011182	Bag3	0.75	DFR
295	3/10/2004	93-EC-2	1011215	Background	0.32	DFR
295	3/10/2004	93-EC-2	1011215	Bag1	0.55	DFR
295	3/10/2004	93-EC-2	1011215	Bag2	0.35	DFR
295	3/10/2004	93-EC-2	1011215	Bag3	0.43	DFR
296	3/10/2004	94-EC-1	1011196	Background	0.33	DFR
296	3/10/2004	94-EC-1	1011196	Bag1	1.32	DFR
296	3/10/2004	94-EC-1	1011196	Bag2	1.00	Fail
296	3/10/2004	94-EC-1	1011196	Bag3	1.96	DFR
297	3/11/2004	93-UC-2	1011216	Background	0.33	DFR
297	3/11/2004	93-UC-2	1011216	Bag1	0.74	DFR
297	3/11/2004	93-UC-2	1011216	Bag2	0.38	DFR
297	3/11/2004	93-UC-2	1011216	Bag3	0.48	DFR
298	3/12/2004	95-UC-1	1011246	Background	0.33	DFR

Record	Date	Vehicle Test	Test ID	Phase/Bag	FTIR N₂O (ppm)	Proposed status
298	3/12/2004	95-UC-1	1011246	Bag1	1.00	DFR
298	3/12/2004	95-UC-1	1011246	Bag2	0.35	DFR
298	3/12/2004	95-UC-1	1011246	Bag3	0.38	Fail
299	3/12/2004	96-UC-1	1011236	Background	0.33	DFR
299	3/12/2004	96-UC-1	1011236	Bag1	0.73	DFR
299	3/12/2004	96-UC-1	1011236	Bag2	0.36	DFR
299	3/12/2004	96-UC-1	1011236	Bag3	1.05	DFR
300	3/17/2004	88-UC-4	1011227	Background	0.33	DFR
300	3/17/2004	88-UC-4	1011227	Bag1	0.69	DFR
300	3/17/2004	88-UC-4	1011227	Bag2	0.48	DFR
300	3/17/2004	88-UC-4	1011227	Bag3	0.60	DFR
301	3/18/2004	88-UC-5	1011265	Background	0.33	DFR
301	3/18/2004	88-UC-5	1011265	Bag1	0.71	DFR
301	3/18/2004	88-UC-5	1011265	Bag2	0.46	DFR
301	3/18/2004	88-UC-5	1011265	Bag3	0.62	DFR
302	3/18/2004	93-EC-3	1011283	Background	0.33	DFR
302	3/18/2004	93-EC-3	1011283	Bag1	0.52	DFR
302	3/18/2004	93-EC-3	1011283	Bag2	0.36	DFR
302	3/18/2004	93-EC-3	1011283	Bag3	0.50	Fail
303	3/18/2004	94-EC-3	1011256	Background	0.33	DFR
303	3/18/2004	94-EC-3	1011256	Bag1	1.47	DFR
303	3/18/2004	94-EC-3	1011256	Bag2	1.07	DFR
303	3/18/2004	94-EC-3	1011256	Bag3	1.98	DFR
304	3/18/2004	96-M089-1	1011240	Background	0.33	DFR
304	3/18/2004	96-M089-1	1011240	Bag1	0.35	DFR
304	3/18/2004	96-M089-1	1011240	Bag2		N/A
304	3/18/2004	96-M089-1	1011240	Bag3		N/A
305	3/18/2004	96-M091-2	1011258	Background	0.33	DFR
305	3/18/2004	96-M091-2	1011258	Bag1	0.42	Fail
305	3/18/2004	96-M091-2	1011258	Bag2	0.41	Fail
305	3/18/2004	96-M091-2	1011258	Bag3		N/A
306	3/18/2004	95-EC-1	1011248	Background	0.33	DFR
306	3/18/2004	95-EC-1	1011248	Bag1	0.60	DFR
306	3/18/2004	95-EC-1	1011248	Bag2	0.32	Fail
306	3/18/2004	95-EC-1	1011248	Bag3	0.36	DFR
307	3/22/2004	96-UC-2	1011297	Background	0.31	DFR
307	3/22/2004	96-UC-2	1011297	Bag1	0.94	DFR
307	3/22/2004	96-UC-2	1011297	Bag2	0.38	Fail
307	3/22/2004	96-UC-2	1011297	Bag3	1.05	Fail
308	3/24/2004	96-EC-2	1011296	Background	0.32	DFR
308	3/24/2004	96-EC-2	1011296	Bag1	0.71	DFR

Record	Date	Vehicle Test	Test ID	Phase/Bag	FTIR N₂O (ppm)	Proposed status
308	3/24/2004	96-EC-2	1011296	Bag2	0.34	DFR
308	3/24/2004	96-EC-2	1011296	Bag3	0.78	DFR
309	3/24/2004	97-UC-1	1011324	Background	0.32	DFR
309	3/24/2004	97-UC-1	1011324	Bag1	0.60	DFR
309	3/24/2004	97-UC-1	1011324	Bag2	0.35	DFR
309	3/24/2004	97-UC-1	1011324	Bag3	0.35	DFR
310	3/25/2004	95-EC-2	1011347	Background	0.33	DFR
310	3/25/2004	95-EC-2	1011347	Bag1	0.62	DFR
310	3/25/2004	95-EC-2	1011347	Bag2	0.34	DFR
310	3/25/2004	95-EC-2	1011347	Bag3	0.37	DFR
311	3/25/2004	97-EC-1	1011323	Background	0.33	DFR
311	3/25/2004	97-EC-1	1011323	Bag1	0.48	DFR
311	3/25/2004	97-EC-1	1011323	Bag2	0.34	DFR
311	3/25/2004	97-EC-1	1011323	Bag3	0.36	DFR

DFR = Data for record

FYI = For your information (non-validated data)

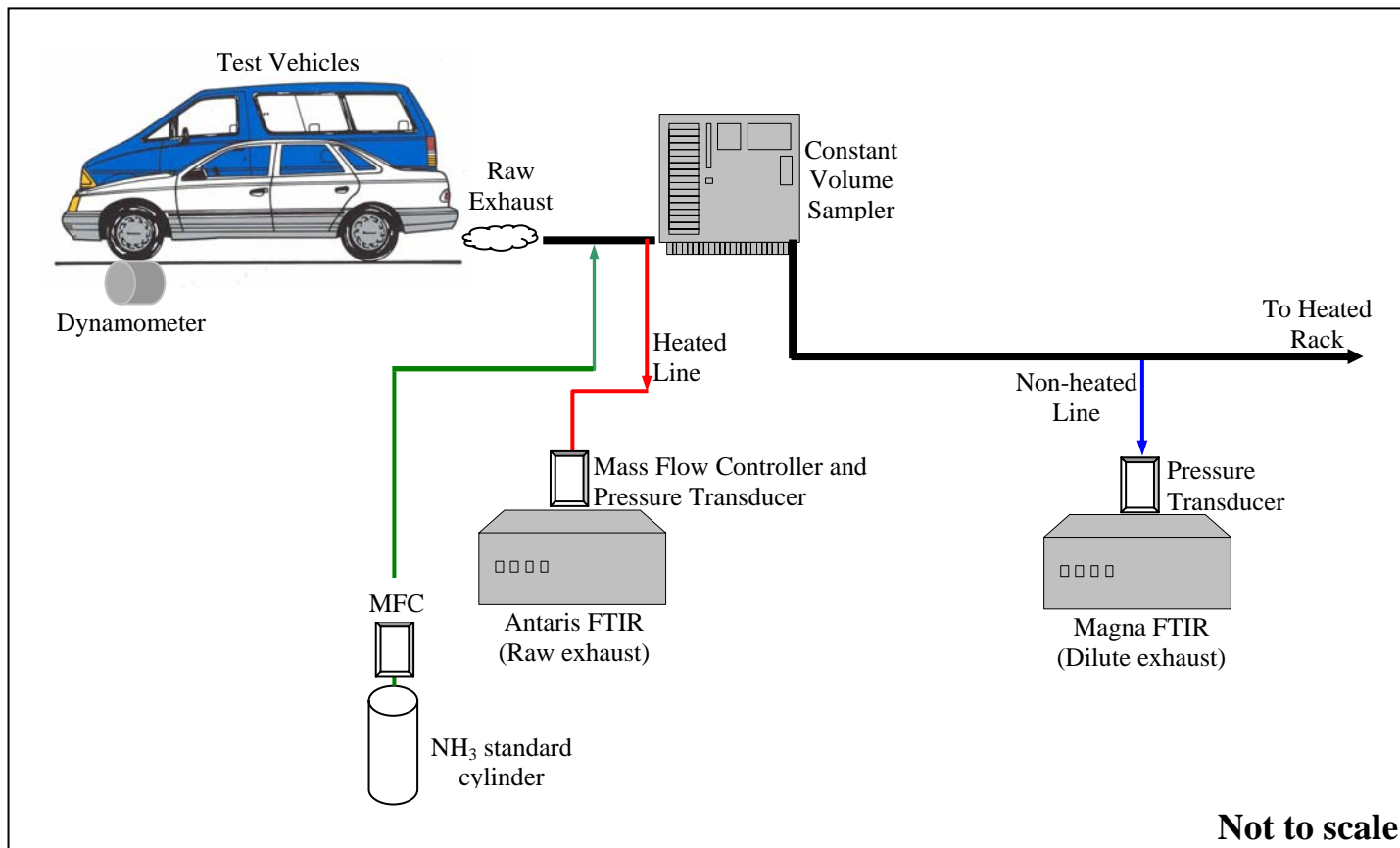
APPENDIX E

REAL-TIME AMMONIA EXPERIMENTS

Number	Date	Vehicle/Experiment	Cycle	Observations
1	1/28/2003	Calibration Check	Injection of 10 ppm NH ₃	Cylinder connected to FTIR
2	1/31/2003	Recovery without vehicle	Injection of 10% NH ₃	CVS at 350 scfm, dilution air at ambient temperature
3	2/5/2003	Recovery without vehicle	Injection of 10% NH ₃	CVS at 350 scfm, dilution air at ambient temperature
4	2/11/2003	Chevrolet Cavalier CNG	FTP-UDDS	CVS at 350 scfm, dilution air at ambient temperature
5	2/14/2003	Recovery without vehicle	Injection of 1% NH ₃	CVS at 350 scfm, dilution air at ambient temperature
6	2/14/2003	Recovery without vehicle	Injection of 1% NH ₃ by pulses	CVS at 350 scfm, dilution air at ambient temperature
7	3/19/2004	Calibration Check	Injection of 10 ppm NH ₃	Cylinder connected to FTIR
8	3/19/2004	Calibration Check	Injection of 3.6 ppm NH ₃	Cylinder connected to FTIR
9	12/15/2003	Recovery without vehicle	Injection of 10% NH ₃	CVS at 1000 scfm, line at ambient temperature
10	12/15/2003	Recovery without vehicle	Injection of 10% NH ₃	CVS at 1000 scfm, heating the line
11	12/15/2003	Recovery without vehicle	Injection of 10% NH ₃	CVS at 1000 scfm, line at 185 F
12	1/26/2004	Recovery without vehicle	Injection of 10% NH ₃	CVS at 500 scfm, dilution air at ambient temperature
13	1/26/2004	Recovery without vehicle	Injection of 10% NH ₃	CVS at 1000 scfm, dilution air at ambient temperature
14	1/26/2004	Recovery without vehicle	Injection of 10% NH ₃	CVS at 500 scfm, heating dilution air
15	1/26/2004	Recovery without vehicle	Injection of 10% NH ₃	CVS at 500 scfm, dilution air at 107 F
16	2/2/2004	Recovery without vehicle	Injection of 10% NH ₃	Minimum CVS flow (160 scfm), dilution air at ambient temperature
17	2/2/2004	Recovery without vehicle	Injection of 10% NH ₃	Minimum CVS flow, heating dilution air
18	2/2/2004	Recovery without vehicle	Injection of 10% NH ₃	Minimum CVS flow, dilution air at 120 F (max. temp)
19	2/2/2004	Recovery without vehicle	Injection of 10% NH ₃	CVS at 330 scfm, dilution air at 108 F
20	2/2/2004	Recovery without vehicle	Injection of 10% NH ₃	CVS at 340 scfm, dilution air at ambient temperature

Number	Date	Vehicle/Experiment	Cycle	Observations
21	2/9/2004	Recovery without vehicle	NH ₃ Injection by pulses	CVS at 1000 scfm, dilution air at ambient temperature
22	2/9/2004	Recovery without vehicle	NH ₃ Injection by pulses	CVS at 500 scfm, dilution air at ambient temperature
23	2/9/2004	Recovery without vehicle	NH ₃ Injection by pulses	CVS at 480 scfm, dilution air at 104 F
24	2/25/2004	Chevrolet Lumina	J test	CVS flow rate = 504 scfm; injecting 4 one-minute pulses of 10% NH ₃ (old)
25	3/1/2004	Chevrolet Lumina	J test	Aborted test. Computer failure
26	3/4/2004	Chevrolet Lumina	J test	CVS flow rate = 500 scfm; 100 C; 650 Torr
27	3/8/2004	Chevrolet Lumina	J test	CVS flow rate = 500 scfm; 100 C; 650 Torr
28	4/6/2004	Chevrolet Lumina	J test	CVS flow rate = 490 scfm; 100 C; 650 Torr
29	4/13/2004	Chevrolet Lumina	J test	CVS flow rate = 490 scfm; 100 C; 650 Torr
30	4/19/2004	Chevrolet Lumina	J test	CVS flow rate = 490 scfm; 100 C; 650 Torr
31	4/21/2004	Chevrolet Lumina	J test	CVS flow rate = 490 scfm; 100 C; 650 Torr
32	4/21/2004	Honda Civic CNG	J test	Preliminary test; CVS flow rate = 490 scfm
33	4/27/2004	Chevrolet Lumina	J test	CVS flow rate = 490 scfm; 100 C; 650 Torr
34	4/27/2004	Honda Civic CNG	J test	Preliminary test; CVS flow rate = 490 scfm
35	4/27/2004	Comparing tails (NH ₃ and N ₂ O)	J test	NH ₃ = 11 ppm; N ₂ O = 5 ppm
36	5/4/2004	Buick (no catalyst)	J test	Preliminary test; CVS flow rate = 490 scfm
37	5/4/2004	Honda Civic CNG	J test	CVS flow rate = 490 scfm; 100 C; 650 Torr
38	5/13/2004	Honda Civic CNG	J test	CVS flow rate = 490 scfm; 100 C; 650 Torr
39	5/13/2004	Chevrolet Lumina	J test	CVS flow rate = 490 scfm; 100 C; 650 Torr
40	5/20/2004	Chevrolet Lumina	J test and recovery	CVS flow rate = 490 scfm; injecting 4 one-minute pulses of 10% NH ₃ (new)

Number	Date	Vehicle/Experiment	Cycle	Observations
41	5/20/2004	Buick (no catalyst)	J test and recovery	CVS flow rate = 490 scfm; injecting 4 one-minute pulses of 10% NH ₃ (new). Problems during first pulse
42	5/20/2004	Honda Civic CNG	J test	CVS flow rate = 490 scfm; 100 C; 650 Torr
43	6/8/2004	Chevrolet Lumina	J test	Comparing raw and diluted exhaust; cold start before catalyst
44	6/8/2004	Chevrolet Lumina	J test	Comparing raw and diluted exhaust; hot start before catalyst
45	6/8/2004	Chevrolet Lumina	J test	Comparing raw and diluted exhaust; hot start after catalyst
46	6/9/2004	Chevrolet Lumina	J test	Comparing raw and diluted exhaust; cold start after catalyst
47	6/9/2004	Chevrolet Lumina	J test	Comparing raw and diluted exhaust; hot start after catalyst
48	6/9/2004	Chevrolet Lumina	J test	Comparing raw and diluted exhaust; hot start before mixing tee
49	6/9/2004	Chevrolet Lumina	J test	Comparing raw and diluted exhaust; hot start before mixing tee
50	6/9/2004	Chevrolet Lumina	J test	Comparing raw and diluted exhaust; hot start before mixing tee



Schematic of the experimental setup (equipment and accessories) for ammonia emissions testing
MFC = mass flow controller